Master of Urban Climate and Sustainability (MUrCS)

The Green Area Ratio as a planning tool for sustainable green infrastructure in a highly dense and arid urban environment

Case study: Lima, Peru

Carol Torres Limache

21 August 2020

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Submitted in partial fulfilment for the requirements of
Master of Urban Climate & Sustainability (MUrCS)

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21 August 2020

Abstract.

Green infrastructure (GI) can simultaneously deliver a wide range of highly beneficial ecosystem services (ESs) for cities. However, in densely built arid environments, implementing GI can worsen water scarcity, limiting its effectiveness as a climate change mitigation measure, especially against urban heat islands (UHIs). The Green Area Ratio (GAR) could be a helpful tool to determine the proportion of functional GI to overcome these issues. However, the tool has been not explored in arid contexts.

Based on the revision of nine existing GAR tools, this thesis determines whether any is suitable for implementation in arid environments, using Lima, Peru as a study case. Lima is a dense megacity with extremely low rainfall, increasing temperatures and scarce green areas. On the basis that none had prioritised water conservation to achieve thermal regulation, a new tool was developed based on scientific evidence and a microclimate analysis with ENVI-met.

The creation of the tool, the GAR Lima, showed that despite aridity, the presence of GI is relevant for Lima´s sustainable development and resilience. However, there is a need to combine it with other surfaces and supporting infrastructure to become sustainable. Such complexity suggests GI should not be considered the main resource to overcome environmental challenges in an arid city and therefore other sustainability approaches should be considered. The application of the tool indicates that arbitrarily increasing the ratio of GI in Lima may not necessarily lead to an improvement of the urban quality, even if it is designed under Xeriscape design principles. Xeriscape may not always result in a higher functionality as some surface combinations may not always result beneficial for thermal regulation, UHI mitigation and further ESs.

While this demands thorough testing, the GAR Lima nevertheless represents a preliminary evidence-based framework for better understanding of how to maximise the ESs delivered by GI in densely built arid urban areas. It is, therefore, a basis for potential implementation.

Keywords: Green area factor, green area ratio, green infrastructure, ecosystem services, arid environments, megacity, urban heat island, water scarcity, Lima, Peru.

This dissertation is my own original work
and has not been submitted elsewhere
in fulfilment of the requirements
of this or any other award.

Carol Torres Limache
21 August 2020

Dedication

To Alexander, my lovely future husband.

Acknowledgements

I would like to acknowledge everyone who played a role in this academic accomplishment. First, my family in Lima, Peru, for their motivation and continuous support on the distance. Special thanks as well to those local experts, who unconditionally communicated with me and shared their knowledge and facilitated information for the development of this thesis.

I would also like to express my gratitude to all the professors of the MUrCS Programme, especially to my supervisor Professor Eeva Aarrevaara as well as Professor Rohinton Emmanuel for their guidance, motivation and continuous orientation throughout the development of this project.

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Glossary

BAF	Biotope area factor
BC	Base case
ENSO	El Niño southern oscillation
EPA	Environmental performance assessment
ES	Ecosystem service
GAR	Green area ratio
GI	Green infrastructure
NBS	Nature-based solution
P	Precipitation
PET	Potential evapotranspiration
SRI	Solar reflectance index
UHI	Urban heat island

1. INTRODUCTION

1.1. RATIONALE

Green infrastructure (GI) has globally demonstrated it can simultaneously deliver a wide range of ecosystem services (ESs). GI can positively impact in habitats and life quality and help cities increase their resilience against various environmental hazards (Benedict and McMahon, 2002; Pauleit et al., 2017). Its implementation in the built environment has, therefore, become a key resource for sustainable development (MVCS, 2017).

However, within densely built arid environments, the allocation of GI represents a great challenge. Limited open space with limited vegetated surfaces can exacerbate the effects of changing temperatures, particularly due to climate change and urban heat islands (UHIs) (Katzschner, 2011). While covering buildings and other urban surfaces with vast vegetation is widely suggested to counteract these threats, within arid environments it can be morally questionable. An intensive increase of GI can paradoxically intensify the vulnerability to droughts and water stress (Doherty, 2017; Nouri et al, 2019; Valencia, ca. 2019). Irrigation can compete with other essential demands for water (Werthmann, 2008) or can come at the expense of high energy demand for greywater treatment which may not necessarily warrant benefits for the public realm (Shaka, 2015). The high cost of vegetation maintenance can even encourage GI´s overprotection or privatisation, negatively affecting its collective dimension and contribution to liveability. Citizens can be deprived from public access to vegetated spaces, and subsequent benefits (ESs) such as leisure and shading, reducing GI's function to be merely decorative (Jönsson, 2016).

Due to the water scarcity, urban GI in arid climates may require to be designed in the most efficient way possible (Ahmadi Venhari et al., 2019). A functional and strategic sense, which includes a sensitive approach to water and the local climate in its implementation, could be key to GI’s role as an efficient tool of the sustainable development of such dense and arid environments (Eisenberg et al., 2014; Erell et al. al., 2011). Practices such as Xeriscape (Yang and Wang, 2017; Chow and Brazel, 2012), irrigation based on treated grey water (Pradhan, 2019) in combination with trees (Karatasou et al., 2006; Chow and Brazel, 2012), green roofs (Speak et al., 2013) and high-reflectance surfaces (Santamouris et al., 2013) as urban surfaces have proved to be potential solutions. However, their performance and contribution to outdoor thermal regulation within arid conditions have yet not been fully understood (Tolderlund, 2010; González-Méndez and Chávez-García, 2020). Some may have limitations under arid conditions (Speak et al., 2013; Van der Meulen, 2019), being also the source of unintended disservices, such as increased temperature if applied at large scale (Yang and Wang, 2017; Chow and Brazel, 2012).

The scale of GI required to achieve effective thermal regulation together with the delivery of other ESs within urban environments seems to be unclear in many cases (Naumann et al., 2011; Szulczewska et al., 2014; Emmanuel and Loncosole, 2015). In addition, limited guidance is available for landscape design in arid environments (Ivanir et al., 2015). Therefore, this thesis proposes the exploration of the Green Area Ratio Tool (GAR) as a resource to reflect the impact of different urban surfaces in the outdoor environment. The GAR could potentially support in the identification and quantification of the ratio of truly functional green areas that achieve thermal regulation and are sensitive to water conservation as well as to other ESs. It can be used as a planning instrument to ensure the maximization of the benefits derived by urban vegetation, reducing arbitrariness in the implementation of GI and ensuring it is justified within densely built arid environments. The GAR tool could, ultimately, contribute to ensure a more sustainable increase of green areas. However, the tool has not been fully explored in arid contexts.

Hence, this thesis proposes the establishment of a GAR tool that can support effectively in this sense, using the city of Lima, Peru, as the scenario for application. Lima is a megacity with extremely low yearly rainfall and increasing temperatures, influenced by El Niño phenomenon and climate change, and with scarce urban green areas distributed unevenly across the city. Due to these conditions, the city is highly vulnerable to droughts and UHIs, and experiences social conflicts around access to potable water and urban green spaces. Despite these challenges, the city remains in constant growth, oriented by development ordinances based on international standards, which primarily compensate increased building density through the increase of the ratio of vegetation on building surfaces. Such international standards may not necessarily be adapted for application in the arid context.

The proposed GAR tool, therefore, aims to serve as a local guide in the implementation of GI, highly sensitive to water conservation and thermal regulation. Such tool will help determine how GI should be implemented to mitigate the most pressing environmental challenges - particularly UHIs in a densely built arid context. This will be developed through the following objectives:

1. Establish the main environmental challenges of densely built arid urban environments from the Lima perspective.
2. Identify which practices and measures are common and suggested at the local and international levels to help mitigate these challenges, particularly through GI.
3. Determine if any existing GAR tool is suitable for application in the Lima context, mainly from a climatic perspective and based on the extent to which the tool had included suitable greenery practices and measures for the arid context.

4. Create a GAR tool sensitive to Lima's main environmental challenges and considering the inclusion of relevant ESs that help mitigate such challenges and the establishment of a ranking that reflects the contribution of diverse urban surfaces and building practices towards the achievement of thermal regulation, water conservation and further ESs.
5. Validate the effectiveness of the resulting GAR tool by applying the tool to representative traditional and sustainable buildings with different densities and ratios of GI, and determine the extent to which the tool can support the local implementation of sustainable GI.

This thesis is based on desktop research and a mixture of qualitative and quantitative methods for collecting and analysing data. Chapter 2 presents key GI-related concepts and certain synergies taking place within the arid environment. It defines the city's environmental profile, including their environmental challenges and the mitigation strategies applied locally and suggested by global literature. This information set the basis to determine the main local goals that the GAR tool should pursue to become an effective tool in the implementation of GI as a thermal regulation strategy within the constraints of water scarcity. The literature review in Chapter 3 outlines previous work on the development of GAR tools internationally, including experiences in arid environments and Lima. Nine existing GAR tools were analysed to identify their rationale and their contribution to the achievement of varied ESs, particularly water conservation and thermal regulation.

Under the conclusion that no previous case could adequately address such concerns, a new GAR tool was proposed based on the revision of local and international documentation about suggested practices for arid and dense urban environments. These practices were given scores through an Environmental Performance Assessment method, following the methodology set out in Chapter 4, which determined their level of contribution to achieve certain ESs. Ideally, the scores against each ES would be determined through experimental methods. However, given the scope of this study, a review of scientific papers was used for this purpose, except for the thermal regulation aspect due to its importance in the local context. Vegetated and non-vegetated surfaces were assessed through a microclimate analysis with ENVI-met 4.4.5 to determine their impact as UHI mitigation strategies under local spatial and climatic conditions.

Ultimately, the GAR tool, described in the results section (Chapter 5), was applied to three buildings to observe how the tool evaluates different types of projects and so-called local "sustainable" strategies in the delivery of ESs. The outcomes, including proposed avenues for improvement and further research, are discussed in Chapter 6 and Chapter 7, presenting conclusions in Chapter 8.

2. BACKGROUND

2.1. KEY CONCEPTS

Urban green infrastructure and ecosystem services in the Lima scope

Green infrastructure (GI) is commonly described as either an network of natural and semi-natural areas (Naumann et al., 2011; UNEP et al., 2014; EC, 2013) or as a benefit for wellbeing (Benedict and McMahon, 2002; Mell, 2009 cited in Pauleit et al., 2017). In Peru, GI is considered a key tool in sustainable landscape design, urban planning and relevant for wellbeing (MVCS, 2017) but the term is often used interchangeably with 'green areas'. Green areas refer to urban public or private spaces reserved for vegetation, including parks or squares but also the open spaces within plots such as private gardens. However, the contribution of these latter in the quantification of the total percentage of vegetated areas is not necessarily always considered, when planning GI changes for an area (Miranda et al., 2015). In this study, GI will be interpreted as an urban network composed by many green areas.

Ecosystem services (ESs) refer to the benefits obtained from the ecosystem, including those derived from urban GI (UNEP et al., 2014). The number and variety of ESs is large. In Peru, the grouping system proposed by Alcamo et al., (2003) (Table 1) has been officially recognised although it contains some crossovers between groups (SERNANP, 2020; Gómez-Baggethun et al., 2013).

In the urban scope, GI does not necessarily shape fully natural spaces. Nature-based solutions (NBSs), for instance green roofs and walls, come as a combination of natural and non-natural materials and surfaces. Given that NBSs contribute to some extent to the same objectives as GI (Pauleit et al., 2017; Eisenberg and Polcher, 2019), benefits derived from combined 'green-grey' infrastructure are also recognised as ESs in this study.

Table 1. Ecosystem services description according to MEA and TEEB (Pauleit et al., 2017)
Provisioning services
Goods, such as food or freshwater, that humans consume or use. In an urban context this may include food production on urban and peri-urban farmland, on rooftops, in backyards and gardens.
Regulatory services
Flood reduction and water purification, that natural systems, such as wetlands can provide. In an urban context this may include the reduction of temperature through shading and heat absorption through evapotranspiration and the reduction of air pollution by removing pollutants through leaves.
Cultural services
Intangible benefits, such as aesthetic, enjoyment or identification with a place. In urban areas recreation and aesthetics are probably the most significant services. This includes GI in parks and other public as well as private green spaces.
Supporting services
Basic processes and functions, such as soil formation and nutrient cycling, that are critical to the provision of the first three types of ecosystem services.
MEA (2005), Barthel et al. (2010), Gómez-Baggethun and Barton (2013) cited in Pauleit et al., 2017

High-albedo and evapotranspiration and their role in densely built arid environments

Aridity means there is less precipitation than what evaporates. That is, the loss of surface water (potential evapotranspiration - PET) exceeds water gain (average annual precipitation - P) (Warner, 2004; Goudie, 2009). Low rainfall limits the possibilities to naturally irrigate vegetation, thus arid environments commonly have scarce vegetation and can be highly prone to hazards such as droughts and desertification (Arup, 2018; FAO, 2020). While deficits in soil moisture and groundwater are part of the nature of arid environments (Goudie, 2009), desertification can degrade the soil to the extent it can no longer support vegetation and wildlife due to the low content of organic matter in the topsoil (Arup, 2018; UNDDD, 2020; FAO, 2020). Apart from being detrimental for agriculture activities, desertification could impact urban areas by encouraging migration, from rural to urban areas (Cherlet et al., 2018).

Beyond aridity, any extreme change in the natural land albedo and reduction of evapotranspiration coming from vegetation foliage (Liu et al., 2018), due to desertification and/or densification could dramatically alter climate. Jackson et al. (1975) and Charney (1975 cited in Zhang et al., 2020) indicated at some point, that at a large scale, the denude of surface could dramatically alter temperatures, even rainfall patterns. Similarly, the ground surface created by urbanisation processes, mostly composed by hard surfaces (e.g. asphalt), can bring a similar effect.

Densification comes along with new ground materials in the urban surface that bring different heat capacities and fluxes, thermal conductivities, albedos, and emissivities. These, along with the increase of anthropogenic heat flux and reduced evapotranspiration, can enhance warming (Jacobson and Ten Hoeve, 2012; Carvhalo et al., 2017; Shandas, 2020). Especially within dense urban geometries with limited air flow this can result in the development of urban heat islands (UHIs) (Duarte, 2016). UHIs can be defined as the increased temperatures experienced in urban areas compared to surrounding rural or non-urbanised areas (Jacobson and Ten Hoeve, 2012; Tsoka et al., 2018).

Therefore, high albedo and evapotranspiration are key resources for thermal regulation. The albedo or reflectance represents the proportion of the incident solar radiation reflected by a surface. Surfaces with high albedo reflect more radiation and absorb less as heat, resulting in a cooling effect at the surface (Karatasou et al., 2006). Evapotranspiration, on the other hand, refers to the transpiration of water extracted by the roots from the soil (ending to the leaves ‘stomata) and the evaporation of the water on the plants’ surface (Bowler et al., 2010 cited in Tsoka et al., 2018). Incident solar radiation is transformed into latent heat which converts water from liquid to gas, resulting in a cooling effect due to lower leaf temperature, air temperature and higher humidity (Katzschner, 2011). Therefore, the denser the vegetation foliage is, the higher the cooling effect.

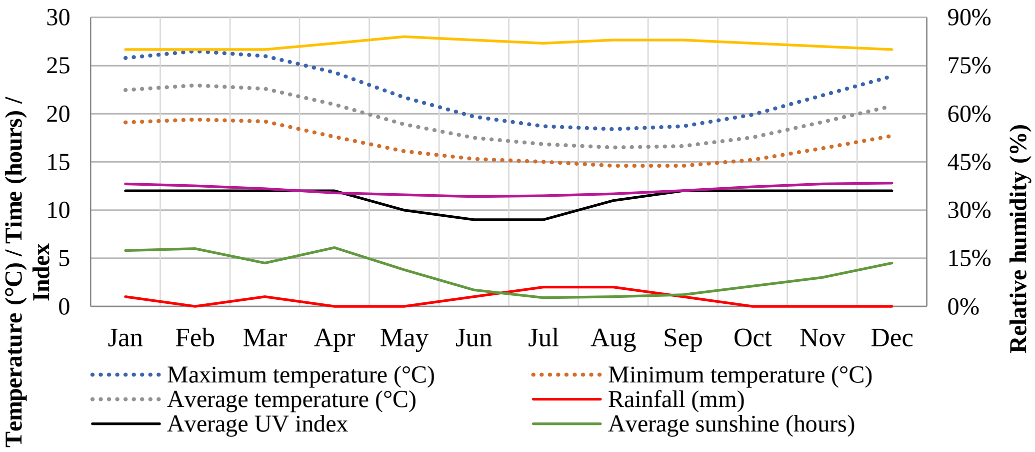
These conditions make urban GI provide the ES 'Thermal regulation', which is commonly seen in cities as a resource to counteract temperature change. Nevertheless, an intensive greening approach in arid environments can also bring disservices (negative outcomes). Intensive increase of GI, and its subsequent demand for irrigation, can exacerbate droughts and water scarcity. Given that globally water saving and conservation is part of climate adaptation plans to prevent the devastating consequences of droughts (Reyes-Paecke et al., 2019), in this study 'Water Saving' is considered as an ES, given that the implementation of GI should support water conservation, especially in urban developments within arid environments.

2.2. STUDY CASE

Lima is a megacity with approximately 10 million inhabitants (MINAGRI and ANA, 2018). The urban area - in conurbation with the province of Callao - is located at the central coast of Peru (12.07° S, 77.04° W) overlooking the Pacific Ocean (Figure 2). It has extremely low annual rainfall, from 5mm to 35mm (MINAGRI and ANA, 2018), with eventual variations due to the El Niño-Southern Oscillation (ENSO).

Under the aridity index (ratio P/PET) Lima has a hyper-arid climate. While aridity is commonly associated to hot climates, it can also occur in cooler climates (Cherlet et al., 2018). As seen in Figure 1, despite being in the tropics, Lima has mild temperatures with cloudy days and high relative humidity (ILPÖ, 2016). The Humboldt sea current cools Lima temperatures while the Andes mountains prevent any tropical warm Amazonian air mass from reaching the coast. Notwithstanding, the high levels of humidity result in higher perceived temperatures (Krellenberg et al., 2014).

Figure 1. Climatic profile of Lima



Based on SENAMHI, 2020; WeatherAtlas, 2020b; Time and Date AS, 2020

Figure 2. Location of Lima

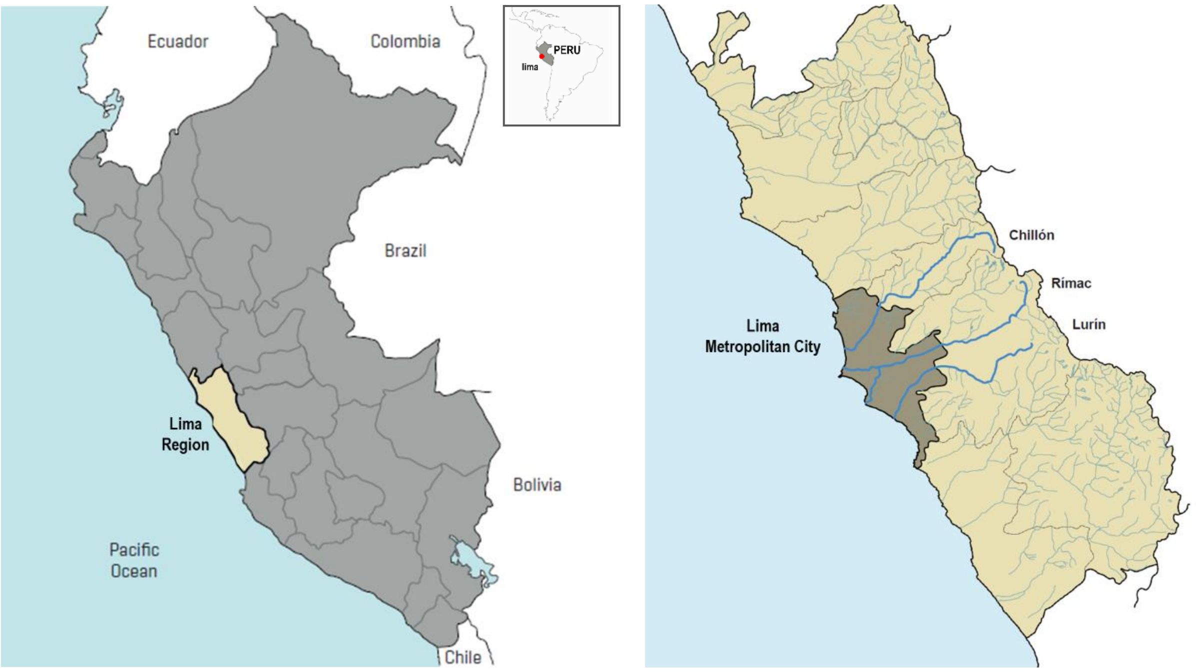


Figure 3. Lima city scape (Merino Reyna cited in ILPÖ, 2016)

2.2.1. ENVIRONMENTAL CHALLENGES

Many cities in developing countries and arid regions are highly vulnerable to a range of different environmental challenges; however, they are considered particularly vulnerable to climate change (Palme et al., 2016). Lima, for instance, is the capital of the world's third-most vulnerable country to this threat (MINAM, 2020).

Given Lima's exponential urban growth, droughts and heat waves are the major climatic concerns in a significant number of districts (PROACC, 2018), however these are related to broader environmental and social challenges. These are described below.

Increased temperatures due to urban heat islands

Approximately 9% of the urban area is considered green area (MML, 2014). However, it seems insufficient to mitigate the development of local UHIs. The literature review indicates there are limited local scientific studies in this regard. However, Barros and Menacho (2014), Soberón and Obregón (2015) and Teruya Revilla (2016) identified UHIs in many areas of the city, principally in those with high ratio of asphalt surfaces and limited vegetation. Barros and Menacho (2014), for instance, identified UHIs with intensity of up to 3.7°C within Lima´s urban area.

This scenario could be exacerbated due to increasing temperatures resulting from climate change and the El Niño effect (Siña et al., 2016). SENAMHI (2009) indicated by 2030 temperatures could rise by a further 0.4°C and minima by up to 0.8°C, compared to 2009 levels. Most recently, Krellenberg (2014) observed an increase in temperature and fewer cold days.

In addition, Lima experiences extreme dangerous ultraviolet radiation values (up to 13) (Ccora, 2015). Although heat waves and UHI are two distinct meteorological phenomena, several studies showed that both are strongly connected and they can also intensify the UHI effects (Carvhalo et al., 2017).

Water scarcity and restricted accessibility to green spaces

Scarce rainfall makes local water supply dependant on seasonal rivers coming from melting Andean glaciers that become considerably contaminated as they reach the urban areas (MINAGRI and ANA, 2018). While the El Niño effect creates uncertainty in the hydrological cycle, a declining trend in the level of rainfall has been recorded (Krellenberg et al., 2014). Due to climate change, this rainfall is expected to decline a further 10-30% by 2030 compared to 2009 (SENAMHI, 2009).

In addition, there is one million people are disconnected from the potable water network (Krellenberg, 2014) and - despite this and local aridity - up to one third of water availability is used for irrigation (ILPÖ, 2016). This disparity around water is reflected in the disproportional presence of green areas per urban district, as illustrated in Figure 4.

On average, there is approximately 3.7 m2 of green area per capita (Lima Como Vamos, 2014). However, affluent districts have approximately 40 times more green area per person compared to others (MINAGRI and ANA, 2018), which has led to social conflicts associated with the rights of citizens to use green areas as public spaces. Due to high costs of irrigation based on potable water, neighbourhoods fence green spaces to limit visitors' use, depriving other citizens to benefit from ESs, such as tree shade and outdoor leisure.

Figure 4. Inequality of green infrastructure (Merino Reyna cited in ILPÖ, 2016)

2.2.2. MITIGATION MEASURES

A variety of measures have been incorporated in Lima's building regulations to face the challenges described in section 2.2.1. Most of these have been established as 'sustainable' ordinances and upgraded building codes. Table 3 shows some representative examples that will be used for this study. Some of these guidelines can be voluntary and rely on international standards. Principally, they mandate the implementation of certain practices as exchange for concessionary loans or permit for additional building density. These practices include high albedo roofs, green roofs and green walls with different soil depths, donation of private area to be converted in public space, xeriscape (defined in Table 2), irrigation using treated domestic greywater and the achievement of sustainable building certifications.

Table 2. The principles of xeriscape

1	Adequate design and planning	"Zoning" according to climate (daylight and wind presence), water requirements (hydro-zoning) and land use. For example, the creation of an "oasis", an area intended to be irrigated, but where efficient irrigation is implemented and therefore results cooler, more attractive and suitable to allocate activities, as long as the species tolerates it under minimal maintenance.
2	Irrigation	Additionally, to the inclusion of efficient irrigation systems such as drip irrigation, sprinklers, humidity sensors and automatic control systems, irrigation should be strategically planned to take place at the coolest moment of the day to avoid it being affected by rapid evaporation due to heat.
3	Mulch	Inclusion of a layer of mulch, bark or stones (gravel) to reduce the growth of herbs and constraint water evaporation from soil. This also helps maintain adequate soil temperature and reduce erosion.
4	Soil Preparation	Soil should not be extremely sandy (it favours rapid water filtration), nor extremely loamy (it favours retention). While the soil conditions can always be improved to favour plant growth, xeriscape fosters the selection of adequate plants over the alteration of soil conditions. It therefore prioritizes the use of locally adapted or native species as they may be already adapted to deal with local soil conditions and long periods of droughts.
5	Limited use of turf	Limit turf to useful spaces where people benefit and determine which grasses will best serve activity needs.
6	Plan selection	Grass cover and manicured lawns should be minimized as they are highly water-consuming and require frequent maintenance such as fertilisers and pesticides. Use only low-water-use plants (e.g. xerophytic), locally adapted or native species as these species adapt better to the conditions of local soil (humidity and composition), and may be naturally drought-tolerant, which reduces irrigation and maintenance over time.
7	Maintenance	Pruning, occasional weeding and pest management, checking that the irrigation system is functioning properly, and adjusting automatic irrigation systems as the seasons change is still needed. However, it is highly reduced in comparison to traditional gardening practices due to the above-mentioned considerations.

Based on: Xeriscapes.net, 2012.; Brescia de Fort et al., 2010; Balbontín López-Cerón, 2012; Arup, 2018; Park&Co,2020; Miller, 2020

Table 3. List of revised local guidelines

Document Name	Denomination/Description	Voluntary	Origin	Year	Source
LEED v4.1 Building Design and Construction	Certification of sustainability	Y	United States	2019	USGBC, 2019
EDGE version 2.1	Certification of sustainability	Y	United States	2019	IFC, 2018
BREEAM SD202 - 1.2:2012	Certification of sustainability	Y	United Kingdom	2012	BRE Global, 2017
MiVivienda Verde	Certification of sustainability	Y	Peru	2020	MVCS, 2020
Technical Code of Sustainable Building (Supreme Decree N° 015-2015-VIVIENDA)	Building code	Y	Peru	2015	Prieto, no date
Ordinance that modifies the Ordinance No. 510 / MM, which establishes, regulates and promotes conditions for sustainable buildings in the district of Miraflores. (Ordinance N° 539-MM-2020)	Sustainable Ordinance	Y	Peru (Miraflores)	2020	MM, 2020
Modification of the Ordinance N°610-MSB Ordinance of sustainable buildings in residential areas in the district of San Borja. (Ordinance N° 623-MSB-2019)	Sustainable Ordinance	Y	Peru (San Borja)	2019	MSB, 2019
Modifying the Ordinance N° 412-MSI, which establishes dispositions to encourage investment and the improvement of competitiveness in the district. (Ordinance N° 437-MSI-2016)	Sustainable Ordinance	Y	Peru (San Isidro)	2015	MSI, 2016
Approval of the Integrated Normative Regulation – RIN of the district. (Ordinance N° 474-MSI-2019)	Ordinance	N	Peru (San Isidro)	2019	MSI, 2019
Law that establishes preventive measures against harmful effects on health from prolonged exposure to solar radiation (Law N° 30102)	Building code (only public buildings)	N	Peru	2013	Congress of Peru, 2013
RNE - National Building Code (Supreme Decree N° 011-2006-VIVIENDA)	Building code	N	Peru	2006	GP and MVCS, 2006
RATyDU - Regulation of Territorial Conditioning and Urban Development (Supreme Decree N° 004-2011 VIVIENDA)	Planning code	N	Peru	2011	GP et al., 2011
RATyDUS - Regulation of Territorial Conditioning and Sustainable Urban Development (Supreme Decree N° 022-2016-VIVIENDA)	Sustainable planning code (upgraded version of RATyDU)	N	Peru	2016	GP et al, 2016
Guide of Bioclimatic Architecture for Educational Buildings 2008	Building code (only schools)	N	Peru	2008	MINEDU, 2008

3. LITERATURE REVIEW

As a matter to determine the suitability of the tool for a densely built arid context, a detailed description of the GAR calculation mechanism and its evolution across cities is presented in the following sections. Only few comparison studies have been developed among previous cases and its applicability in urban contexts outside its city of origin have been mostly present in academic experiments. In this regard, the work of Vartholomaios et al. (2013) and Roehr and Laurenz (2008) stand out as they summarized common aspects, identified relevant differences among most of the cities in Table 4 and discuss certain mechanisms in case of local adaptation. While limited research on the adaptation or application of the GAR to the arid context was found, the work Miranda et al. (2015) (section 3.3) suggested the GAR's potential applicability in Lima. Therefore, these research works represent a valuable basis for potential adaptation of the tool and its application to the Lima context.

3.1. THE GREEN AREA RATIO

The Green Area Ratio (GAR) is an area-based calculation and planning tool that facilitates decision-making through the assessment of the functionality and contribution to sustainability of the GI implemented in private outdoor areas of urbanised areas (Roehr et al. 2008; Lakes and Kim, 2012; Vartholomaios et al., 2013; Kaczorowska, 2014; Juhola, 2018). The GAR was originally conceived to improve the 'ecological effectiveness' of outdoor spaces of private plots by determining the proportion of area with a positive effect in the ecosystem (Landschaft Planen und Bauen and Becker Giseke Mohren Richard, 1990). It, therefore, facilitates the calculation of the ratio of areas that contribute positively to the improvement of the functioning of the ecosystem.

It originates from the Biotope Area Factor (BAF) applied in Berlin but has been officially integrated in the legislation of many cities principally in Europe and North America. Consequently, it appears in literature under varied names. Table 4 shows a list of 9 GAR tools applied worldwide and some key climatic characteristics about their location. According to many authors, it has proven it is simple, flexible and effective (Keeley, 2011; Vartholomaios et al., 2013; Kaczorowska, 2014; Grant, 2017; Evokari, 2018; Peroni et al., 2019) and applicable to different types of buildings, land uses, densities and spatial scales (Keeley, 2011; Cidlowski, 2011; Vartholomaios et al., 2013).

The GAR´s main components are briefly presented in Table 5. These and its calculation method (Figure 5) have mostly remained consistent across cities (Vartholomaios et al., 2013). The GAR's main objective was originally to support the creation of biotopes (habitats) in Berlin by calculating the ratio of vegetated surfaces to sealed surfaces (Landschaft Planen und Bauen and Becker Giseke Mohren Richard, 1990). However, throughout its application in different cities this objective has evolved.

The contribution of ecologically functional areas to the ecosystem has been interpreted differently by every city and mostly taken from their interest in certain ESs that support the achievement of local environmental and urban objectives. For instance, the Helsinki's tool accounts for functionality and maintenance aspects (Juhola, 2018), the tool of Stockholm considered food cultivation (Kaczorowska, 2014), Seattle's tool included considerations on the reduction of energy demand and CO_2 emissions (Roehr et al. 2008), while other cities considered urban aesthetics (Vartholomaios et al. 2013).

Figure 5. Simplified diagram of a site development to demonstrate the GAR calculation method (Grant, 2017)

$$\frac{(0.7 \times 36) + (0 \times 14) + (0.2 \times 16) + (1 \times 30) + (0.7 \times 4)}{100}$$

Score = 0.61

Target = 0.5

Site = 100m^2

		Factor	Area (m^2)
	Extensive green roof	0.7	36
	Non-permeable surface	0.0	14
	Permeable paving	0.2	16
	Woodland / trees on deeper soil	1.0	30
	Tree in shallow soil / tree pit	0.7	4
			100

Table 4. Cities with GARs and associated city statistics

	Name	Acronym	Origin	Source revised	Köppen–Geiger climate classification (1)	Average annual rainfall (mm) (2)	Population density (people per km^2) (3)
1	Biotope Area Factor Biotopflächenfaktor	BAF	Berlin, Germany	Landschaft Planen und Bauen and Becker Giseke Mohren Richard, 1990	Cfb	571	4,114
2	Green Space Factor Grönytefaktor	GSF GYF	Malmö, Sweden	Malmö stad, 2020	Cfb	602	2,198
3	Green Space Factor	GSF	Stockholm, Sweden	Stockholms stad, 2015	Cfb	528	3,749
4	Green Space Factor	GSF	Southampton, United Kingdom	Southampton City Council, 2015	Cfb	780	5,067
5	Urban Greening Factor	UGF	London, United Kingdom	Greater London Authority, 2017	Cfb	602	6,945
6	Green Factor Tool	GFT	Helsinki, Finland	City of Helsinki Environment Centre, 2016	Dfb	655	1,883
7	Green Infrastructure Score	GI-Score	North West England (NWE), United Kingdom	Community Forest Northwest, 2010	Cfb	829 (4)	5,661 (4)
8	Green Area Ratio	DCGAR	Washington DC, United States	Department of Energy and Environment, 2017	Csc	1009	4,457
9	(Seattle) Green Factor	SGF	Seattle, United States	City of Seattle, 2020	Csb	952	1,169

Based on (1) Kottek et al., 2006; (2) Weather Atlas, 2020a; (3) City Population, 2020 | (4) Information provided for Manchester, UK

Table 5. Description of the components of the Green Area Ratio tool as indicated by literature

Base Formula	The principle of calculation of the GAR is area-based. It consists of adding together areas with the same surface type and multiplying the sum by a corresponding weighting (factor). This is done for all floor and roof-surface types and additionally the area of green walls. Then, the total of the weighted surface type areas is divided by the total plot (floor) area, resulting in a GAR-Score (ratio). This calculation is commonly developed with an editable spreadsheet-based calculator provided by the local authority.
Practices and GAR Weightings	The GAR offers a set of varied 'Practices' composed by urban surfaces, pavers, gardening techniques, and design measures including spatial functions of free choice for selection and location (Juhola, 2018). The practices and their corresponding weightings are established by the planning authority (Keeley, 2011) and differ from place to place (Vartholomaios et al., 2013). In its origins, the GAR considered all surface areas, not only those covered by vegetation on undisturbed soil, even though these often had the highest significance for protecting the function of ecosystems. Hence, it assigned a 'weighting' depending on the type of surface (of the practice) (Landschaft Planen und Bauen and Becker Giseke Mohren Richard, 1990), as some may contribute more (or less) to achieve ecological effectiveness (objectives). The 'Practices' are weighted according to their relative ecological significance for the city (Vartholomaios et al., 2013). Such 'weighting' works as a factor in the formula and reflects in a general way the environmental performance of the surface and the services provided on-site (Keeley, 2011).
GAR-Target	As part of implementing a GAR, it is often accompanied by numeric targets, which represent "the minimum percentage of parcel area that must be devoted to green infrastructure and provide environmental services" (Keeley, 2011). Like the weightings, these are established by the municipal planning authority (Keeley, 2011). For instance, the BAF targets varies according to site land use (e.g. residential, commercial, public facility, etc.) and occupancy index of the lot (Landschaft Planen und Bauen and Becker Giseke Mohren Richard, 1990). The targets facilitate the comparison of the computed ratio (GAR-Score) to the objectives of the city (GAR-Target), which reflects "the impact of individual green structures in relation to the sustainability goals they have set for the city" (Juhola, 2018).

3.2. COMPARISON STUDIES

Vartholomaios et al. (2013) identified a significant alteration in the base formula in some tools. This consisted in the integration of a 'layering' calculation method to additionally factor characteristics that may not have been initially considered by previous tools. Kruuse (2011) indicated that this - in the case of Malmö, for instance - ensured an area of grass covered by trees (shading) resulted in a higher score than an area of grass with no tree cover.

The 'Practices' as well as the factors also presented some modifications. Vartholomaios et al., (2013) pointed out the addition of a bonus-point system (extra practice list) named 'green-points'. In the tool of Malmö, this system grants points simply for considering the implementation of a practice or mitigation measure, rather than for the quantity of area the practice encompasses. This has been applied mainly to 'Practices' that cannot be measured through an area-based calculation, such as considerations on expert advice, recycled material for construction and waste composted (Kruuse, 2011).

Table 6. Summary of main objectives according to authors

Author	Cities observed	Objectives Identified
Roehr and Laurenz (2008)	Berlin, Malmö, and Seattle	• Safeguarding and improving microclimatic and atmospheric hygiene • Safeguarding and developing soil functions and water balance • Creating and enhancing the quality of plant and animal habitats • Improving the residential environment as well as reducing energy demand and CO_2 emissions
Vartholomaios et al. (2013)	Berlin, Malmö, Seattle, Stockholm, Southampton, and North West England	• Urban climate regulation • Reduction of energy and water consumption • Flood control and restoration of the hydrological cycle • Preservation and enhancement of wildlife habitats • Improvement of urban aesthetics

3.3. EXPERIMENTAL APPROACHES

Discussions about the application of the GAR in arid environments or cities like Lima in terms of density or climate are limited. However, there are some discussions presenting its potential application in cities outside the city of origin.

Greece

Vartholomaios et al. (2013) proposed the application of the GAR in Greece. Through the revision of local planning regulations and their approach to landscaping and paving 'Practices', the authors questioned local landscape design guidelines and identified deficiencies in the delivery of ESs. For instance, some revealed limited specifications regarding the quality and suitability to the context of vegetation. As well, they identified grating mechanisms in the form of ‘environmental bonuses’; for example, to reward with permits for higher density the implementation of green roofs or lower plot coverage– similar to the case of sustainable ordinances in Lima described in section 2.2.2.

Given the local existence of UHIs and flood risk due to the high quantity of impermeable surfaces with limited GI, Vartholomaios et al. (2013) suggested a GAR tool could increase the amount of vegetation, distribute it more evenly, and thereby, incentivise ‘Practices’ that regulate local urban microclimate, whilst maximizing the climatic and ecological benefits provided by GI. However, they noted it should not be simply imported but optimized to suit the local climate and be extensively tested. Therefore, they built a GAR for Greek cities, based on the revision and comparison of six existing GAR tools.

As shown in Table 7, their comparison analysis identified high weightings in other GARs are assigned to ‘Practices’ such as green roofs and walls, vegetation on connected soil, water features and the preservation of large trees, being the crown size a measure and determining attribute of their effectivity over the area. Based on this information, Vartholomaios et al. (2013) proposed a GAR tool.

However, there is limited explanation on how their ‘Practices’ and weightings were established and contribute to mitigate the environmental challenges they indicated. This is despite the apparent arbitrariness of how a GAR´s components (‘Practices’, weightings, and targets) are determined being a recognised general weakness of most GAR tools. These are often based on ‘expert’ opinion, in some cases, without transparency (Keeley, 2011), poorly supported (Barton, 2016) or contrary to evidence from scientific studies (Huang et al., 2015).

A similar gap was also identified in the work of Roehr and Laurenz (2008). The authors proposed the application of the GAR tool of Seattle in Vancouver. Despite the authors’ acknowledgement of the existence of previous tools, they do not clearly indicate why the Seattle tool is a suitable tool to help on the achievement of ESs of interest of Vancouver.

Table 7. GAR-tool comparison and proposed tool by Vartholomaios et al. (2013)

	Berlin	Malmö	Seattle	NW England	Southampton	Stockholm	Greece (3)
Vegetation on shallow unconnected soil	0.5	0.7	0.1	0.4	0.4	0.3	0.2
Vegetation on deep unconnected soil	0.7	0.9	0.6	0.6	0.6	1.2	0.2
Vegetation on connected soil	1.0	1.0	0.6	1.0	1.0	0.2	0.4
Water surfaces	N/A	1.0	0.7	0.7	1.0	N/A	1.0
Collection / retention of stormwater	0.2	0.2	1.0	0.7	1.0	N/A	N/A
Permeable pavement and partially sealed areas (no vegetation)	0.3	0.2	0.2/0.5 (1)	0.2	0.2	N/A	0.3
Areas covered with gravel and sand	0.3	0.4	0.2/0.5 (1)	0.4	0.4	N/A	0.5
Green pavers	0.5	N/A	0.2/0.5 (1)	0.4	N/A	N/A	0.5
Structural soil systems	N/A	N/A	0.2	N/A	N/A	N/A	N/A
Shrubs	N/A	0.2	0.3	0.3	0.3	0.2	0.4
Tree - small	N/A	1.0	0.3	0.4	0.4 per m2 of canopy cover	1.0	0.7
Tree - medium	N/A	1.5	0.4	0.4		1.5	0.8
Tree - large	N/A	2.0	0.4	0.4		2.4	1.0
Tree - protected/ exceptional	N/A	N/A	0.8	0.4		3.0	N/A
Green roofs	0.7	0.6	0.4/0.7 (2)	0.7	0.7	0.1/0.4 (2)	0.7
Vegetation on vertical surfaces	0.5	0.7	0.7	0.6	0.6	0.4	0.6
Bonuses for specific vegetation qualities	no	no	yes	no	no	yes	yes

(1) for shallow and deep substrate of gravel accordingly (2) for low and high vegetation height accordingly
(3) As per "List of proposed features and their individual factors" in proposed tool for Greek cities

Peru

Miranda et al. (2015) indicated the implementation of the BAF (Berlin's tool) could help increase the existing low percentage of GI in outdoor private and public spaces produced by deficiencies in Peruvian urban and building regulations. They referred to the BAF-target concept as a potentially useful urban parameter and suggested requesting it when proposing new developments, changing land use and as part of building permit applications or certifications. However, the authors indicated achieving the targets should not motivate, nor allow the increase of building height (and subsequent higher population density), since it denatures and limits the targets' positive impact on environmental quality.

The authors indicated the BAF brought benefits to Berlin, in terms of the achievement of certain ESs such as reduced flood risk, improved microclimate and cleaner air. However, they did not provide evidence of this. Like Vartholomaios et al. (2013), they noted the importance of adapting the tool to suit local conditions and highlighted this in particular for Peruvian coastal cities with extreme low yearly rainfall and constraints to preserve vegetation.

However, Miranda et al. (2015) do not go further on how the adaptation of the BAF could be done. Notwithstanding, they applied it to two existing residential buildings in Lima and calculated their BAF-Scores. As observed in Table 8, the scores were significantly lower as the value (BAF-Target) established by the Berlin's tool (0.3) and were used to support their claim for the improvement of local building regulations. According to the authors, developments with bigger open areas and more ecologically effective GI should be established.

Table 8. BAF-Scores calculated for two projects by Miranda et al. (2015)

	Building 1	**Building 2 (Palas)**
District	Not indicated	Chorrillos
Year	Not indicated	2014
Total Plot Size (m2)	121.42	2574.4
Density Type	Not indicated	Medium
Residential Type	Not indicated	Multifamily
Total Inhabitants	Not indicated	570
Inhabitants per Dwelling	4	Not indicated
Dwelling size (m2)	85	Not indicated
Percentage open space	30%	Not indicated
Area open space (m2)	36.43	Not indicated
Floors	Not indicated	8
Vegetated Area (m2)	Not indicated	326.72
Connected / Not connected to Soil (m2)	Not indicated	92.2 / 234.52
BAF Ecological Effective Area (m2)	**1.96**	**281.62**
BAF Score	**0.0161**	**0.1094**

4. METHODOLOGY

4.1. DETERMINATION OF THE NEED FOR A NEW GAR TOOL

As noted in the previous chapters, for a GAR tool to be effective, it should be suitable for the local context and sensitive to local concerns and goals (ESs) of the city where it is applied. However, there is limited information on how a GAR tool, its 'Practices' or weightings should be determined, particularly if a tool is being applied outside its original context.

Therefore, to determine whether any existing tool contributes effectively to water conservation and thermal regulation – major concerns in Lima (section 2.2.1) **-** a detailed revision of the GAR tools of the nine cities presented in Table 4 was conducted. These cases are very well documented in official literature (primary sources such as calculators, handbooks, reference documents, etc.) as well as in secondary sources such as scientific publications.

As a first approach, the annual average rainfall of each city was compared to that of Lima. Then, the nine cases were analysed through a qualitative analysis to record which ESs were pursued by each case through the explicit information provided by their calculators and official literature. All 'Practices' included in previous GARs calculators were listed together in a spreadsheet to identify the way they contribute to achieving certain ES, which was recorded as 'Indicated Service' (**Appendix 1**). Additionally, the ESs not explicitly mentioned in 'Practices' but expressed in the literature as objectives were also recorded.

The information collected was analysed to determine whether any particular GAR suggested 'Practices' that dealt adequately with the key environmental challenges of Lima. Derived from section 2.2.1, special attention was given to the ESs labelled 'Social cohesion', 'Recreation', 'Water Saving' and 'Thermal regulation'. This was used as the basis to determine whether a previous GAR could have as well prioritised such ESs and could thereby be applied or adapted, or ultimately be the basis for a new tool.

This analysis helped also gather and simultaneously assess the varied characteristics of previous GAR tools, including additional information such as weightings, calculation units and other attributes. Some information in the calculators required translation since it was not offered in English, therefore it was subjected to the author's interpretation.

4.2. CONSTRUCTION OF A GAR TOOL

On the basis that a new GAR tool is needed, the ESs and the 'Practices' the tool should include (including urban surfaces, pavers, gardening techniques, and design measures as described in Table 5) were established through a qualitative analysis of the local guidelines and challenges presented in Chapter 2, following the method of analysis applied to existing GARs. The ESs and practices from the local context and existing GARs were combined, then summarised based on local priorities. They were then subjected to an 'Environmental performance assessment' (EPA) to establish their 'Final weightings'.

4.2.1. SELECTION OF ECOSYSTEM SERVICES

In addition to the ESs that contribute to water conservation and thermal regulation, the ESs of major interest of Lima were identified through the analysis of local concerns and interests expressed in the information contained in sustainable construction guidelines and regulations (Table 3). These were contrasted with ESs from existing GARs to identify crossovers and to ensure the proposal encompasses a variety of environmental challenges typical of urban areas (as previous tools) while maintaining a local perspective.

The resulting final ESs were then ranked with a 'ES Prioritisation factor' that was later included in the EPA (Figure 6). High-priority ESs were given a factor of 3, with the remaining ESs received a factor of 1. It was assumed that 'three times the initial relevance' could significantly boost the value of the resulting "Final factors' of the most relevant 'Practices'. This was executed as a way to ensure the 'Practices' delivering highly relevant ESs were prioritised, by showing high "Final factors' that could encourage their selection during decision-making.

4.2.2. SELECTION OF PRACTICES

As indicated in Table 5, the label 'Practices' can refer to different types of urban surfaces including vegetated and non-vegetated surfaces and pavers. The set of 'Practices' for Lima was defined based on the revision of:

- local sustainable construction guidelines (presented in section 2.2.2)
- typical building practices and materials selected based on the authors local knowledge
- 'Practices' from existing GAR tools that suit the local context or contributed to achieve relevant ESs

To help compare 'Practices', they were categorised under 'Practice Group' and 'Practice Type' according to the explicit information available in their descriptions. Their elements of composition, technology type and engineering such as detention systems, green walls, reflective surfaces, etc. were recorded and classified primarily based on physical attributes.

The three lists of 'Practices' were combined then summarised to remove duplicates and irrelevant or unsuitable 'Practices' and adjusted to suit the local conditions.

4.2.3. ENVIRONMENTAL PERFORMANCE ASSESSMENT

An environmental performance assessment (EPA) was undertaken to assess the effectiveness (performance) and contribution of each 'Practice' to achieve each selected ES. The EPA was based on the approach of Keeley (2011), who used this method to present the calculation of the 'Final weightings' of the GAR of Berlin (BAF). As observed in Table 9, Keeley (2011) qualified a set of 'Practices' in a range from 'None' to 'High-very high' depending on how effectively each contributed to certain ES.

Table 9. Environmental performance assessment of Berlin GAR - Keeley (2011)

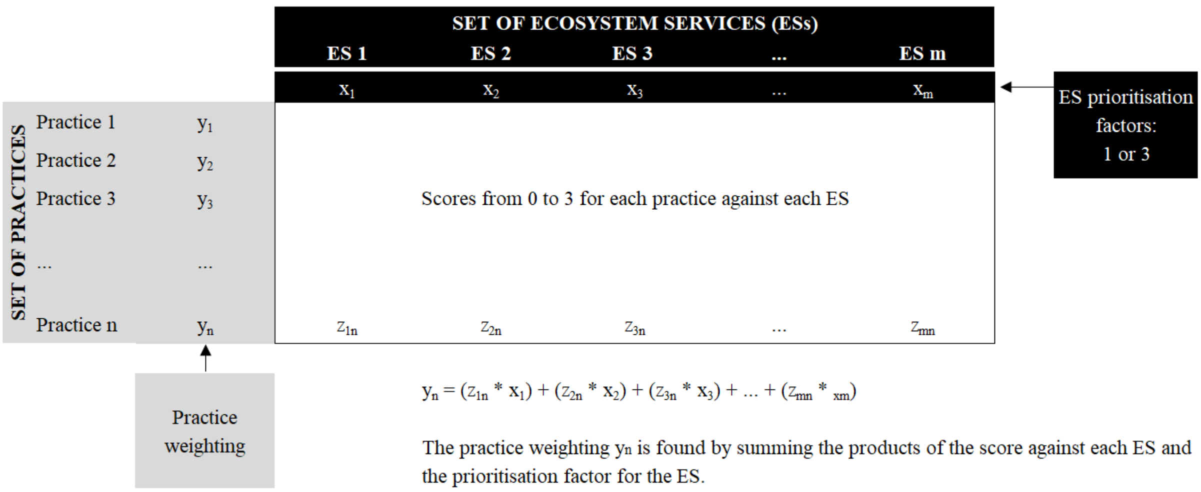
	Evaporation	Water infiltration storage	Soil functions	Habitat	Filtration of air pollution	Recommended weighting
Impermeable surfaces	None-little	None	None	None	None	0.0
Impermeable surfaces, from which all stormwater is infiltrated on property	None-little	High -very high	None	None	None	0.2
Non-vegetated, semi-permeable surfaces	Little	Little	Little	None-little	None	0.3
Semi-permeable paving supporting vegetation	Moderate	Moderate	Moderate	Little	Little	0.5
Green facades	Moderate - High	None	None	Moderate-high	Moderate - high	0.5
Areas underlain by shallow subterranean structures	Moderate - High	None	Little	Moderate	Moderate - high	0.5
Areas underlain by subterranean structures	High	None	Moderate	Moderate	High	0.7
Green roofs	Moderate - High	None-Little	Little	Moderate - high	Moderate - high	0.7
Vegetated areas	High - very high	Moderate	High - very high	High - very high	High	1.0

Therefore, an assessment framework as shown in Figure 6 was built. This consisted in the following components:

- Ecosystem services (black area) identified in section 4.2.1, including their ‘Prioritisation factors’
- ‘Practices’ (grey area) identified in section 4.2.2

The ‘Practices’ were scored based on how well each contributes to achieve each ES and indicated for each ES in the ‘white area’ of the table presented in Figure 6. However, distinct from Keeley, scores between 0 (lowest) to 3 (highest) were used to maintain a numerical approach across all the assessment. The score achieved by each ‘Practice’ (in each ES-column) was then multiplied by the corresponding ES ‘Prioritisation factor’ and subsequently, all scores were summed to obtain the ‘Final Practice Weighting’ of each ‘Practice’. In order to achieve similarities with previous tools, these ‘Final weightings’ were then adjusted to fit within a ‘0.00 to 1.00’ weighting scale, so the highest possible Practice´s weighting was 1.00.

Figure 6. Assessment framework to determine the ‘Practices’ weightings



Ideally, the scores for each ‘Practice’ against each ES would be determined through an experimental scientific method (e.g. in situ measurements). Given the scope of this study, the scoring was instead based on available scientific literature collected from electronic sources and scientific platforms such as Science Direct and Elsevier and special consideration was given to local studies or focused on similar environmental and social concerns.

However, given the relevance of UHI mitigation in this study - as pointed out in section 2.1.1 - for this ES a microclimate analysis with ENVI-met 4.4.5 was conducted to support available literature.

4.2.3.1. MICROCLIMATE ANALYSIS

The main methods of reducing the UHI (high reflectance surfaces, evaporation from surfaces and vegetation, and shading) are highly subjected to the influence of variables such as thermal capacity of the material, humidity, ventilation (local winds) and urban fabric (Karatasou et al., 2006; Eisenberg and Polcher, 2019). Therefore, different urban scenarios were modelled with the ENVI-met 4.4.5 software package under local climatic and spatial conditions.

ENVI-met 4.4.5 simulates multiple interactions of the atmosphere with urban structures (ENVI-met, 2019) based on the insertion of numerical inputs (attributes) of materials, vegetation and climate. It has been previously used in similar studies focused on urban greenery (Tsoka et al., 2018; Ahmadi Venhari et al., 2019). It can be a helpful tool for urban climate analysis, provided that appropriate model data are used and its limitations are recognised (Tsoka et al., 2018). Using available local data with ENVI-met should, therefore, ensure a more precise ES score is attributed to each 'Practice'.

The difference in air temperature (cooling or warming effect) was measured using ENVI-met. The capacity of a 'Practice' to perform as a thermal regulation strategy and to reduce UHI can be estimated by determining the impact of the ''Practice''' surface in air temperature over the area where it was implemented (urban canopy layer: street canyons or roof tops) (Schwarz et al., 2012).

The model

As seen in Figure 7, a uniform urban fabric based on similar spatial conditions as in Lima was modelled. This arrangement is easily found across the city and was therefore considered sufficient for the purpose of this analysis. The model consisted of 25 blocks distributed in a layout of 5 by 5. Each block was 20m by 20m, with a height of 15m and street width of 10m.

Material application

Streets, walls, and roofs areas referred to in this assessment are defined in Figure 7. A base case (BC) scenario, consisting of typical buildings materials (red terracotta tile roof, concrete walls and footings, surrounded by asphalt streets) as shown in Figure 8 was established. The material attributes (thermal properties, albedo and other physical attributes) were maintained as suggested by the software database in almost all cases. Where required, custom materials were created to complement the standard ones.

Since the principal aim was to observe variations in air temperature at the pedestrian level, the 'Practices' selected for the EPA were applied to the BC as street surfaces (replacing asphalt) one at a time to develop one scenario per 'Practice' and simulate its impact. The effect of including green walls, trees and shrubs in streets was measured by analysing the temperature change after adding these units within the area of streets (and surrounding walls in the case of green walls). The inclusion of green roofs with different soil depths (extensive and intensive) and reflective surfaces was expected. Hence, further scenarios were considered to assess their impact at the street level – and at the roof level if pertinent.

Simulation

The simulation was conducted under consistent atmospheric conditions as indicated in Table 10. Since Lima has different microclimates (Eisenberg et al., 2014) and limited meteorological stations within the urban area, the meteorological station located within the dense urban area of the district Jesus María, considered of high demand for urban development (ASEI, 2019 cited in Huanachin 2019), was selected. Initial meteorological conditions were sourced from Eisenberg et al. (2014) and MML (2008 cited in IMP, 2012). The model was run for six hours to allow to reach steady state, before measurements were taken for 24 hours from midnight on 23 December 2019 (the day where peak sunlight occurs).

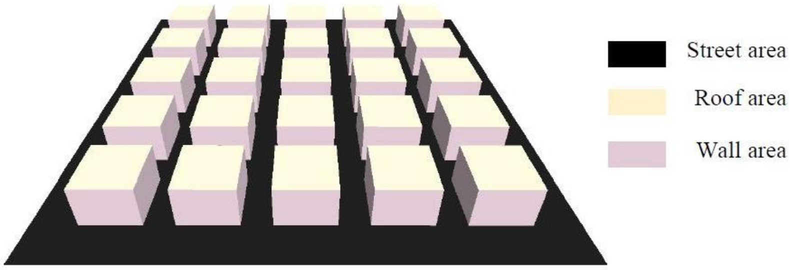
Measurement

The air temperature was measured at the street level (2.5m height above the ground level) from a central area (coordinate 14;14) of the model. Where 'Practices' were applied to roofs, measurements were also taken above roof level (17.5m).

The air temperature measured at each hour of the day was compared to the input temperature data in ENVI-met. The average temperature difference across the day was determined. Based on these results, the surfaces were then ranked from lowest to highest and grouped in four groups according to the proximity of their values in order to assign a weighting. These were contrasted against measurements at certain points in the day:

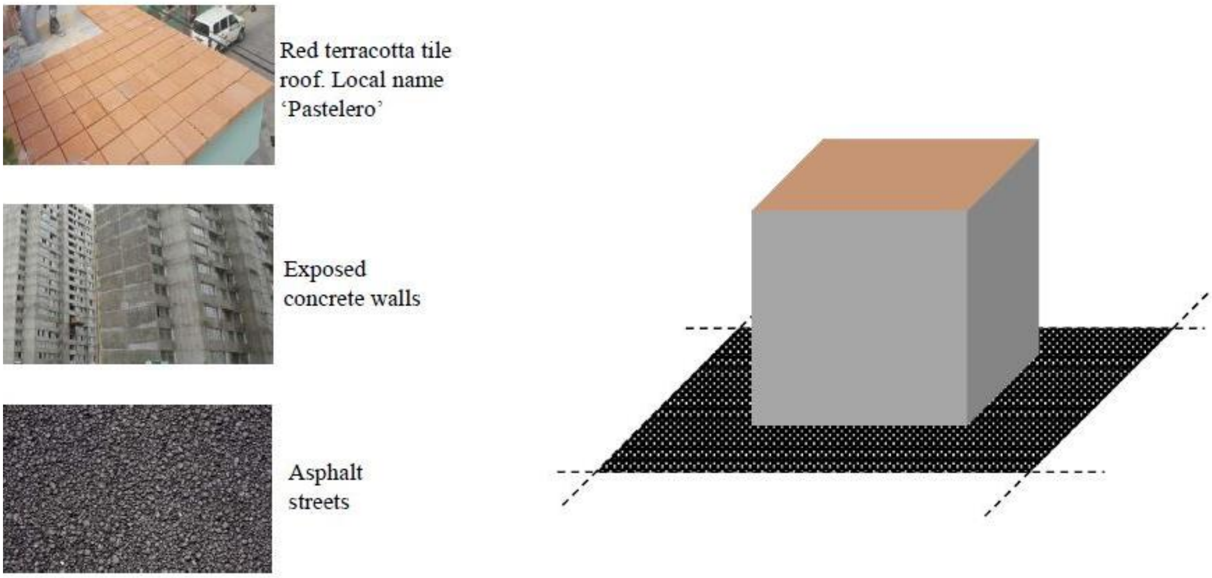
- At 12:00, when the sun angle is highest
- At 16:00, when the input temperature was highest
- At 20:00 to observe the evening effect

Figure 7. Local urban morphology and definition of surface areas for ENVI-met analysis



Setting	Type	Parameter	Value	Units
Model geometry	Model dimensions	x-grids	34	
		y-grids	34	
		z-grids	8	
	Size of grid-cell	dx	5	m
		dy	5	m
		dz (base height)	5	m
		dz of lowest grid cell is split into 5 sub-cells		
	Resulting model size	x	170	m
		y	170	m
		z	40	m

Figure 8. Characterisation of the base case



Source: CONSTRUYE J&C E.I.R.L. (2020) and Chau (2019)

Table 10. ENVI-met input conditions used in simulations

Setting	Type	Parameter	Value	Units
Model location	Location name		El Campo de Marte, Jesús María 15072, Peru	
	Position on Earth	Latitude (deg.+N-S)	-12.07	
		Longitude (deg.-W+E)	-77.04	
	Reference Time Zone	Name	Peru Standard Time	
		Reference longitude	-75.00	
Simulation settings	Start and duration of model run	Start date	22 December 2019	
		Start time	18:00	
		Total Simulation Time	30	h
	Forcing		Simple forcing	
	Simulation type		Advanced	
Initial meteorological settings	Wind	Wind speed at 10m height	5	m/s
		Wind direction	225	° from north
		Roughness length	0.01	(as default)
	Atmosphere temperature	Minimum	17	° C
		Maximum	24	° C
	Relative humidity at 2m	Minimum	79	%
		Maximum	88	%
Initial soil conditions	Soil humidity	Upper layer (0-20cm)	70	%
		Middle layer (20-50cm)	75	%
		Deep layer (50-200cm)	75	%
		Bedrock layer (below 200cm)	75	%
	Initial temperature	Upper layer (0-20cm)	19.85	° C
		Middle layer (20-50cm)	19.85	° C
		Deep layer (50-200cm)	19.85	° C
		Bedrock layer (below 200cm)	19.85	° C

4.3. APPLICATION OF THE TOOL

The GAR tool was validated by assessing representative traditional and sustainable building projects. This also facilitated the evaluation of different levels of 'greenery'.

The first was based on the building 'Palas' (Table 8), a project considered to follow a sustainable approach and analysed by Miranda et al. (2015) under the BAF tool. The study provided sufficient information about its landscape design such as quantity of green area and types of surfaces implemented. Further details about the building were collected from public marketing information.

Two other projects were selected through internet research of local property developments. Details such as plot size, land use, building layout, size, regulations applied, etc., were taken from publicly available sources (e.g. building images, satellite pictures, marketing brochures and plans, etc). According to this data (Figure 9), one was developed under the design principles established by a local sustainable regulation ('Olavide') (Ordinance N°437-MSI and N°474-MSI) and one under 'traditional' design measures ('Huaylas'). The projects are representative examples of local residential developments in terms of area, density, layout, building materials and landscape techniques. They are also located in highly dense and central urban districts of Lima, also considered of high demand for development (ASEI, 2019 cited in Huanachin, 2019).

In all cases, plans were reconstructed based on this data and assumptions were made where there was missing information. Hence, they do not necessarily reflect what was built. Any conclusion from this research should not be interpreted as judgements over any particular development but considered as general information.

A GAR-Score was calculated for each of the three projects. In addition, a number of hypothetical 'retrofitting' options were considered for 'Olavide', principally following the 'Practices' selected in section 4.2.2 (such as water sensitive design approaches, high albedo coatings, green roofs, etc.), to observe the level of impact in their GAR-Score.

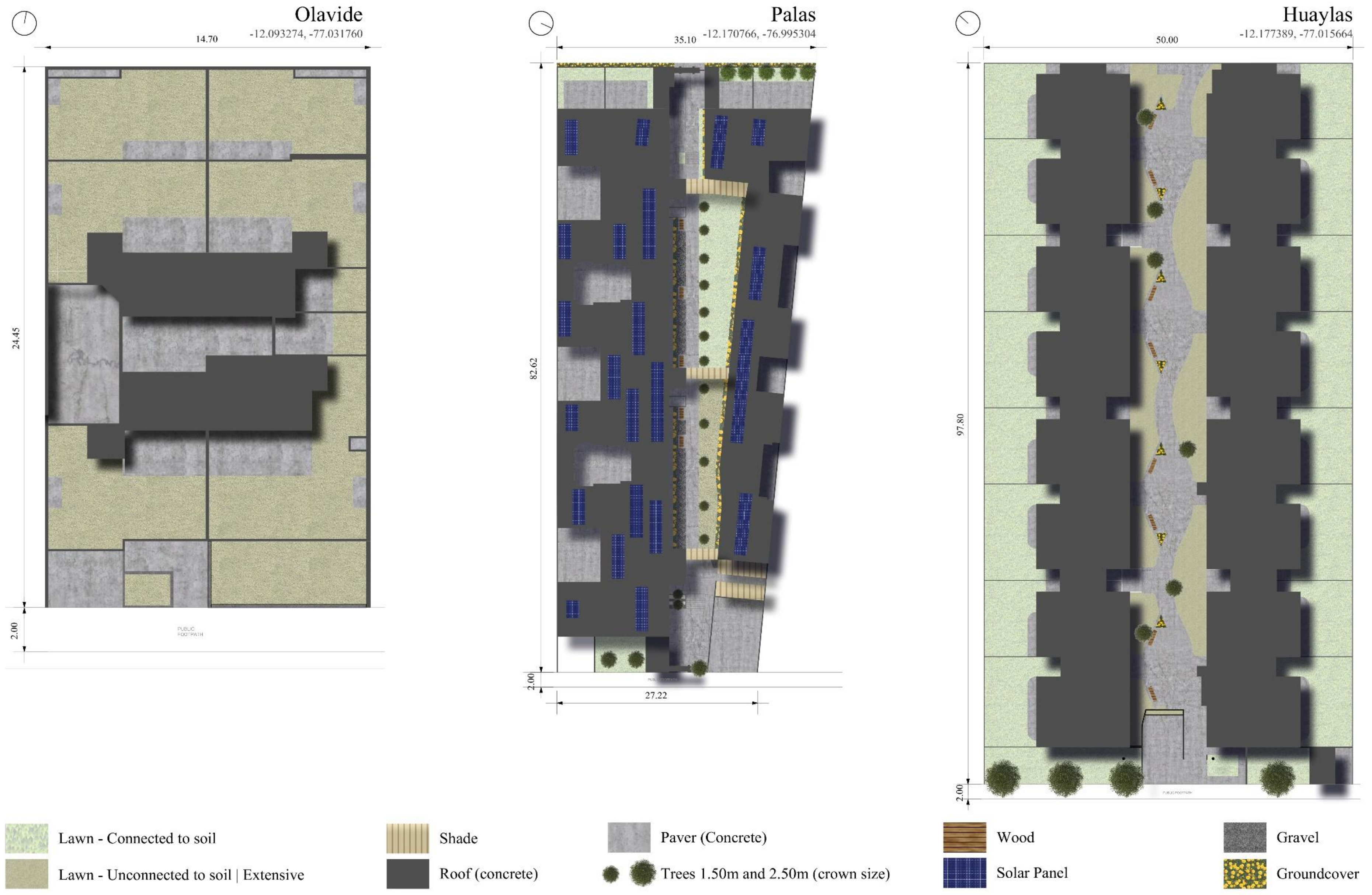
While the number of cases in which the tool was applied is limited, and no GAR-Target is proposed in this study, it is sufficient to observe the level of sustainability achieved by traditional and sustainable local approaches.

Figure 9. Profile of buildings to test the new GAR tool

ID Project	Olavide
District	San Isidro
Year	2020
Type	Residential
Plot size	approx. 360 m2
Classification for this study	**SUSTAINABLE** (Consistent with N° 437-MSI and N°474-MSI)
Photo/Source	EE Inmobiliaria, 2020

ID Project	Palas
District	Chorrillos
Year	2014
Type	Residential
Plot size	2574.40 m2 (Miranda et al., 2015)
Classification for this study	**SUSTAINABLE** (According to Inversiones Tarpuy, 2014)
Photo/Source	Inversiones Tarpuy, 2014

ID Project	Huaylas
District	Chorrillos
Year	approx. 2005
Type	Residential
Plot size	approx. 4882 m2
Classification for this study	**TRADITIONAL** (Due to building age)
Photo/Source	Trovit, 2020

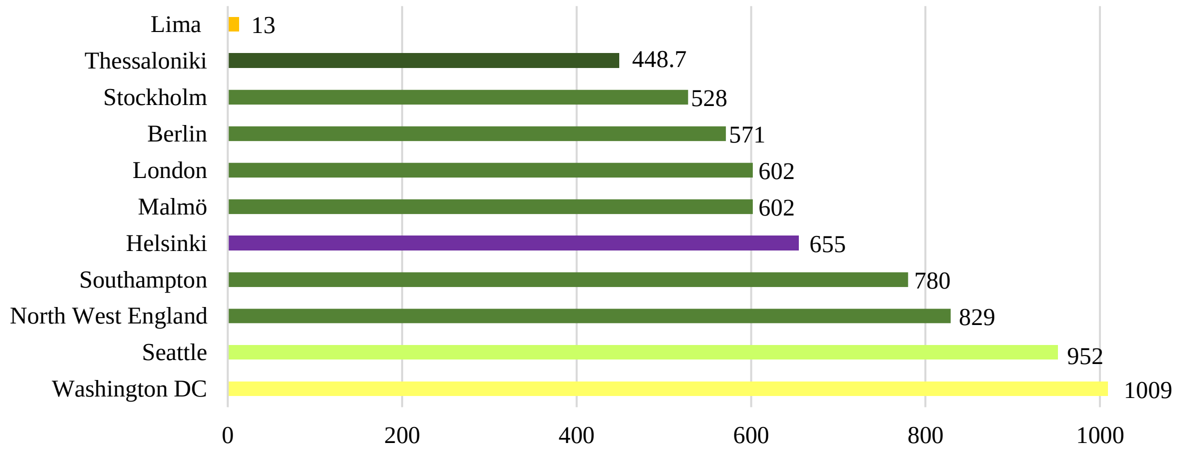

Olavide
-12.093274, -77.031760
14.70
24.45
2.00
Palas
-12.170766, -76.995304
35.10
82.62
2.00
27.22
Huaylas
-12.177389, -77.015664
50.00
97.80
2.00
Lawn - Connected to soil
Lawn - Unconnected to soil | Extensive
Shade
Roof (concrete)
Paver (Concrete)
Trees 1.50m and 2.50m (crown size)
Wood
Solar Panel
Gravel
Groundcover

5. RESULTS

5.1. KEY DIFFERENCES AMONG CITIES

Lima is considerably drier than the cities where a GAR has been applied (including the experimental approach in Greece) and it is the only city with an 'arid' climate (as per the Köppen–Geiger climate classification - Figure 10). The other cities have temperate climates, except Helsinki which has a warm summer continental or hemiboreal climate.

Figure 10. GAR cities - Annual average rainfall (mm) and Köppen–Geiger climate classification



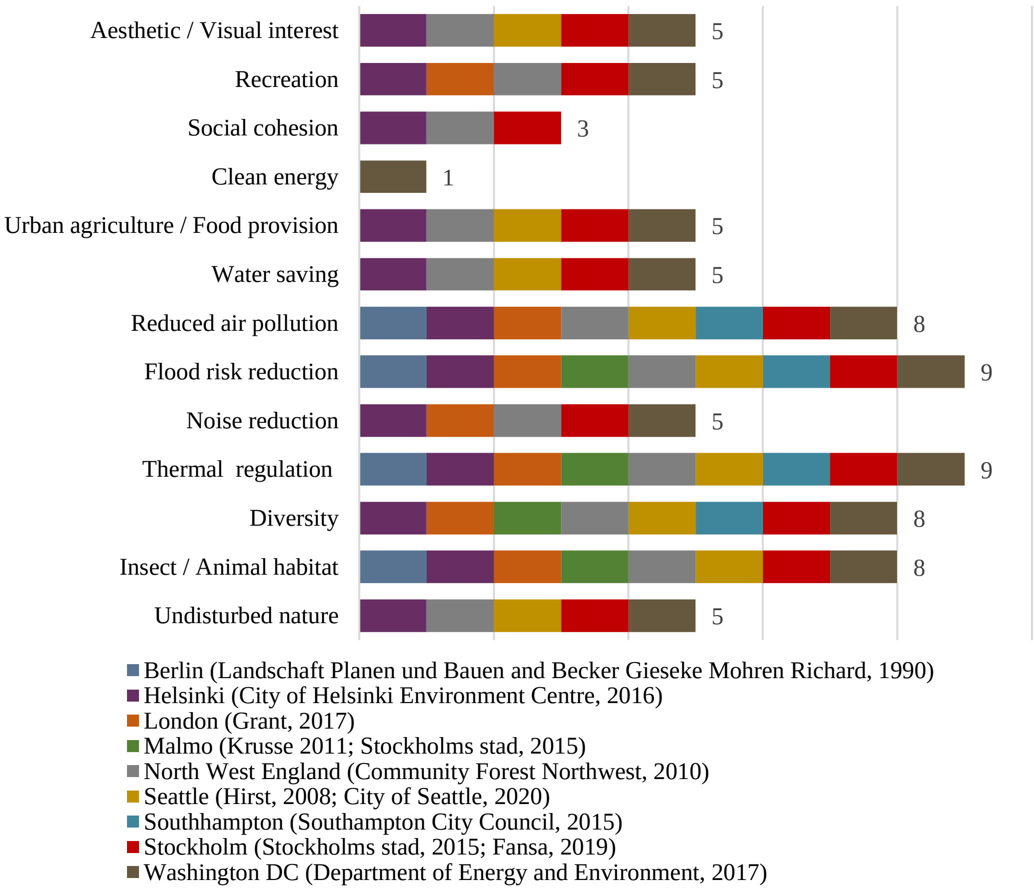
Based on SENMAHI, 2020; Weather Atlas, 2020a; Kottek et al., 2006

The results of the qualitative analysis of GARs to record the ESs pursued by each case are presented in **Appendix 1**. 215 'Practices' were identified, with 87 'Practices' explicitly linked to 12 different ESs. However, the revision of official GAR-literature indicated interest in an additional ES: 'Reduced Air Pollution', resulting in a final set of 13 ESs.

Figure 11 shows the ESs pursued by each city as indicated by the official literature. While all cities indicated interest in 'Thermal Regulation' and 5 in 'Water Saving', according to the literature, this was not directly reflected in all the calculators. Only 3 cities included 'Practices' specifically targeted to shading and cooling. Moreover, these 'Practices' considered temporary shade and had high dependence on water for cooling purposes. Similarly, only 3 cities considered 'Practices' related to 'Water Saving' but these were linked to using stormwater for irrigation.

In the absence of constraints on water availability and rainfall, or concerns about UV-radiation, these may not represent major complications. However, for Lima, these are key concerns. It was therefore concluded that no previous GAR tool would effectively help achieve the ESs of most importance for Lima and therefore the construction of a new tailored GAR-tool was developed.

Figure 11. Varied interest in ecosystem services according to official GAR-literature



5.2. COMPOSITION OF THE NEW TOOL AND ENVIRONMENTAL PERFORMANCE ASSESSMENT

5.2.1. SELECTED ECOSYSTEM SERVICES AND PRIORITISATION

The results of the analysis of local concerns and interests from local guidelines are presented in **Appendix 2**. Only 12 out of the 13 ESs previously identified were of interest for Lima. The 13th ES, ‘Noise Reduction’, was not explicitly mentioned. Notwithstanding, all 13 ESs were included in the EPA.

The ESs defined based on the common attributes identified in the ‘Practices’ are shown in Table 11. Some definitions for local ‘Practices’ varied compared to those from existing GARs. Further, some crossovers between the ESs ‘Social Cohesion’ and ‘Recreation’ were identified. According to Alcamo et al. (2003) (section 2.1) this is likely to happen within the service group ‘Cultural’. Therefore, for practical purposes these were combined and taken as one ES to the EPA.

The final set of ESs, including prioritisation factors and definitions used, is shown in Table 12. Given the relevance of considerations about water saving, the implementation of surfaces that contribute in thermal regulation whilst keeping a collective approach – as outlined in section 2.2.1 – ‘Social Cohesion and Recreation’, ‘Thermal Regulation’ and ‘Water Saving’ were given the highest prioritisation factors (3).

Table 11. Comparison of types of 'Practices' for ecosystem services pursued by local guidelines and existing GARs

	Ecosystem Service	Local guidelines	Existing GARs
1	Flood risk reduction	Practices that support retention, detention, infiltration, drainage of stormwater, such as raingardens, bioswales, green roofs, etc.	
2	Noise reduction	Not explicitly mentioned	Practices that created pleasant sounds coming from water bodies and attributed to the presence of vegetation as barriers
3	Thermal regulation	Practices that reduce urban heat island with reflective surfaces and high albedo or shading structures and trees	Practices that reduce temperature through the presence of water or shading structures and trees
4	Reduced air pollution	Attributed to the presence of vegetation	
5	Diversity	Practices that considered diversity of vegetation species within the landscape design	
6	Undisturbed nature	Practices that considered preference for the selection of local (native) species	Practices that considered the preservation of existing and native nature such as trees with diverse canopy size and preference for local species
7	Insect/Animal habitat	Practices that considered the inclusion of elements that protect animal and insect habitats by being exclusively targeted to feed and offer shelter such as bug feeders or branches	
8	Urban agriculture / Food provision	Practices that facilitate vegetated spaces to grow vegetables, or selection of species that provide fruits	
9	Water saving	Practices that considered the selection of drought-tolerant vegetation or included an efficient irrigation system such as sprinklers, drip irrigation, smart meters, etc.	Practices that considered the selection of drought-tolerant vegetation or facilitate the collection or reserve of water captured from rain
10	Clean energy	Practices that considered integrating renewable energy devices as part of the design	
11	Aesthetic / Visual interest	Practices that resulted ornamental and visible, preferably from pedestrian areas	
12	Social cohesion	Practices that facilitate social activities such as common areas, accessible (without barriers) for public use, visible at ground floor with amenities for human interaction or permanency (e.g. benches, terraces, etc.)	Practices that facilitate social activities such as common areas
13	Recreation	Practices conceived to host leisure activities such as sports, playgrounds or similar within the project	Practices conceived to host leisure activities such as sports, playgrounds, or excursions within the project

Table 12. Assigment of prioritisation factors and assessment criteria used in the environmental performance assessment				
Service Group	**N°**	**Ecosystem Service**	**Prioritisation Factor**	**Assessment criteria**
Regulating	1	Flood risk reduction	1	The capacity of a practice to support on the retention, detention, infiltration and drainage of stormwater and river flooding
	2	Noise reduction	1	The capacity of a practice to reduce noise.
	3	Thermal regulation	3	The capacity of a practice to perform as an Urban Heat Island (UHI) mitigation strategy by either cooling or producing a minimal warming effect in air temperature over the area where they implemented.
	4	Reduced air pollution	1	The capacity of a practice to reduce air pollution.
Supporting	5	Diversity	1	The capacity of a practice to increase biodiversity.
	6	Undisturbed nature	1	The capacity of a practice to encourage the preservation of existing trees.
	7	Insect/Animal habitat	1	The capacity of a practice to host animal and insect habitat (biotopes).
Provisioning	8	Urban agriculture / Food provision	1	The capacity of a practice to host agriculture activities at an urban scale.
	9	Water saving	3	The capacity of a practice to guarantee limited water resources are needed and reduce dependency on potable water.
	10	Clean energy	1	The capacity of a practice to generate clean energy during its lifetime.
Cultural	11	Aesthetic / Visual interest	1	The capacity of a practice to contribute to the increase of the attractiveness of the urban environment, through the increase of the quantity of natural ornamental elements in the landscape, while delivering positive emotions and sensorial experiences.
	12	Social cohesion and recreation	3	The capacity of a practice to host social and facilitate leisure activities (individual or collective) with amenities for human interaction

5.2.2. SELECTED PRACTICES

Local sustainable construction guidelines, typical building practices and 'Practices' from previous GAR tools were classified based on the 'Practice Group' criterion shown in Table 13.

Table 13. Criterion applied for grouping practice: label 'Practice Group'

Practice Group	**Grouping Criteria**
Surface System	Horizontal and vertical surfaces, which may be vegetated or non-vegetated, permeable, or impermeable, sealed or partially sealed surfaces, pavers, groundcovers or water bodies
Vegetation Unit	Vegetation elements (trees and shrubs) that can be implemented in isolation and facilitate dispersed vegetation and could be counted as individual units. Due to their shape and natural dimensions they do not necessarily generate a horizontal vegetated mass; indeed, they perform as vertical elements
Shading Unit	Structures intended to provide shade and perform as human comfort shelter within the environment. They can be vegetated, but are not trees
Functional Surface	Surfaces or units which have a specific function which is inherent to its design or intended use and not necessarily related to its physical composition. Such functions include drought tolerance, reduction of disturbance of nature, intended use of the surface etc.
Building Certification	Certification systems targeted to buildings
Hosting Unit	Landscape elements that benefit or facilitate habitat, comfort, and favour the development of life. Principally targeted to strengthen the development of fauna (animals and insects)
Stormwater Management System	Systems whose primary function is to reduce runoff by promoting filtration and infiltration of water on ground, and to reduce the volume of stormwater or improve runoff by supporting detention, reservation, collection and/or drainage of stormwater. These systems include techniques, design principles or any other element with components (material properties, dimensions, etc.) or engineering (layer systems, composition structure, etc)

This grouping criterion helped develop a summary (**Appendix 4**) that subsequently was adjusted to remove duplicates and irrelevant or unsuitable 'Practices' and adjusted to suit the local conditions. The final list is presented in Table 15. In this process, the following notable amendments were made:

- Three 'Practice Groups' were omitted.
    - 'Building Certifications' was omitted since the 'Practices' embedded in them were already accounted for
    - For 'Stormwater Management System' it was decided that surfaces would be assessed based on their materials and functions only, and specific systems for stormwater management not disaggregated, due to the scant rainfall in Lima
    - 'Hosting units' were accounted for as a 'Functional surface'
- Under 'Surface Systems'

    - Materials which are out of the local context and scale (e.g. eco-bridges and Finnish rock) were omitted and similar systems were combined
- Under ‘Vegetation Unit’, rather than specifying different tree sizes canopies (small, medium or large) and using number of trees as the unit of measure, one single ‘Tree’ practice was included calculated based on square metres of canopy area at maturity. This was more precise but still retained flexibility to reintroduce a unit concept (as in seen in previous GARs), if required.

The grouping criterion helped also organise ‘Practices’ within a layering-calculation system (Figure 12), to capture the assessment benefits discussed by Vartholomaios et al. (2013) and Kruuse (2011). This allows different attributes of one single ‘Practice’ (as observed in section 2.2.2 e.g. accessibility, soil depth, reflectivity, etc.) that contribute to different ESs, to be captured as layers performing over a ‘Surface System’. This resulted in a number of ’Functional Surfaces’:

- ‘Intended Use’ captured attributes ‘Accessibility / Experimental’ and ‘Ornamental / Visible’ that conditioned some ‘Practices’ such as green roofs and other vegetated spaces, as well as ‘Practices’ that serve as ‘Hosting Units’ (bug feeders, birdbox, etc) and agricultural ‘Practices’
- ‘Public access/ use’ captured the concept of donation of private area for public space observed in some local guidelines
- Rather than defining multiple ‘Practices’ for different surface types and soil depths, the ‘Soil Connection’, ‘Functional Surface’ facilitates the combination of the specific ‘Surface System’. This allows different soil depths of vegetated surfaces, including green roofs, to be captured, without having to include multiple different surface systems to account for different soil depths and vegetation covers. Instead, a green roof would be characterised by its ‘Surface System’ (e.g. ‘Groundcover’ or ‘Lawn’) as well as its soil depth (‘Soil Connection’). While there are different ‘soil connection’ definitions, three types were eventually included as described in Table 14 based on local information

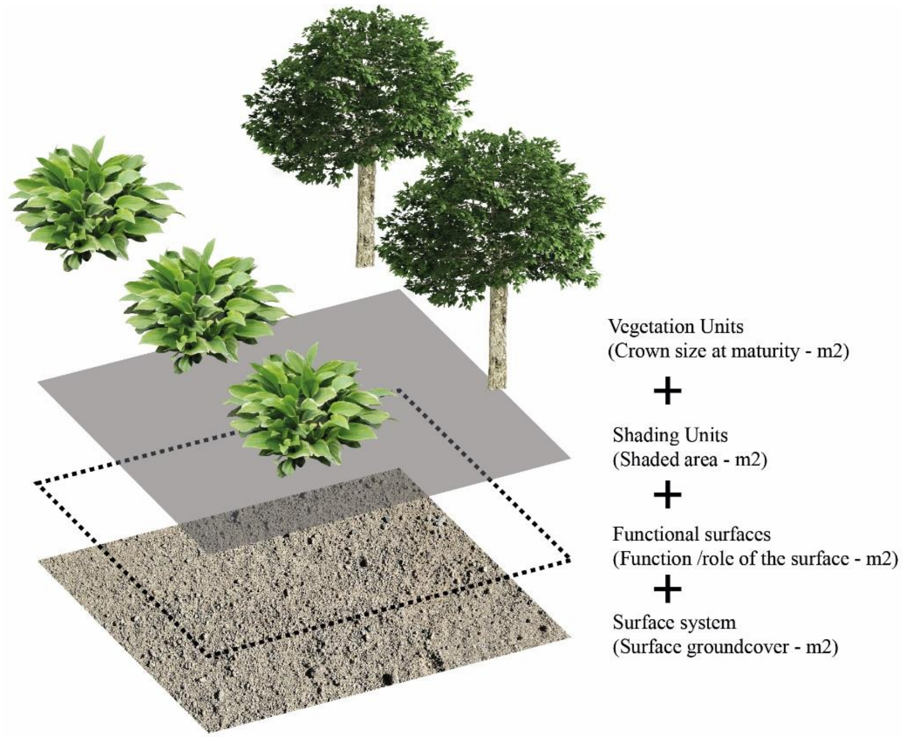
Table 14. Definitions of soil connection (Haaker, 2020)

Soil Connection	Soil depth
Connected Soil	No subterranean structure
Unconnected – Deep soil (incl. Intensive green roof)	More than 20cm soil depth above constructed surface
Unconnected – Shallow soil (incl. Extensive green roof)	Up to and including 20cm above constructed surface

- ‘Reflective Surface’ was included as a ‘Functional Surface’ since reflectivity can perform as an addition (layer) applied on a variety of different surface materials as well as being a property of the surface itself

- Preservation of trees was also captured as a 'Functional Surface'.

Figure 12. Layering approach proposed for the new GAR tool



The 'Native' requirement for vegetation was not considered for the EPA, given the limited local, public and official guidance literature on this respect. Information on which species are well-adapted or native of Lima was found only in one official public source related only to trees (See MML, 2013). Only LEED v4.1. referred to specific handbooks (e.g. Practice N° 17), however relevant only to the United States context. In the absence of this resource, the usage of native species is suggested, but no particular assessment was conducted.

5.2.3. PRACTICE WEIGHTINGS

Table 15 shows the final practice weightings, derived from the environmental EPA (Table 16) and adjusted so the highest practice weighting is 1.00.

For nine ESs of the total twelve ESs, scores were given to relevant 'Practices', depending on the nature of the ES. The scores are shown in Table 17 while the full criteria applied can be found in **Appendix 5**. The results of the microclimate analysis, used to determine the practice scores for the 'Thermal regulation', are outlined in section 5.2.3.1

'Practices' could not be assessed against the remaining three ESs. The revision of scientific documentation revealed that the effective delivery of 'Reduced Air Pollution', 'Diversity' and 'Noise

Reduction' was highly wide and dependent of external variables out of the control of the practice, such as microclimatic conditions and the spatial geometry around the practice. Their relevance for Lima was not clearly established, including other relevant aspects. For instance, the source or type of pollutants (of noise and air) were not specified, nor the scale of impact expected. Also, a definition for the scale of 'diversity', including scale, specie (flora or fauna) could not be identified. Even under assumptions supported by local documentation, the identification of detrimental outcomes likely to happen if spatial arrangements or the scale of the intervention are not clearly defined, led to the conclusion that these ESs should not be considered. More details are provided in **Appendix 5**.

In the 'Final weightings', 'Wetland' (associated with water treatment) was the practice with the highest weighting, due to it receiving maximum scores for multiple ESs. The next highest weightings under 'Surface Systems' were for 'Bare soil', 'Mulch' and 'Sand' (0.7) followed by 'Groundcovers' (0.67). 'Vegetation units' also received high scores: 0.78 for 'Tree' and 0.67 for 'Shrub'. This is because they delivered similar ESs. 'Lawn' received a lower weighting of 0.56 due to its typical high-water demand. The most common building materials, 'Concrete' and 'Red terracotta tile', received weightings of 0.33.

Table 15. Set of 'Practices' and 'Final weightings'

Practice Group	Practice Type	Practice	Final Weighting
Surface System	Permeable	Bare soil	0.70
		Gravel	0.63
		Green wall	0.33
		Groundcovers	0.67
		Lawn	0.56
		Mulch	0.70
		Sand	0.70
	Semipermeable	Combined green/grey surface (e.g. block grass, grass grid, etc.)	0.41
		Permeable paver (preferably unbound)	0.52
	Impermeable	Artificial turf	0.41
		Asphalt	0.33
		Concrete	0.33
		Impermeable paver (bound)	0.33
		Red terracotta tile	0.33
		Solar PV	0.56
		Wooden deck	0.52
	Water Bodies	Water features (incl. fountains, water mirrors, ponds, etc)	0.52
		Wetland (as water treatment plant)	1.00
Vegetation Unit		Tree	0.78
		Shrub	0.67
Shading Unit	Shading measure / structure	Shading structure	0.48
		Shading structure with vegetation	0.48
		Shading structure with solar PV	0.70
Functional Surface	Intended use	Area intended for recreation in donated public/semi-private spaces (e.g. playground, sports areas within donated public spaces or multi-family shared spaces, etc.)	0.33
		Area intended for social interaction in donated public/semi-private spaces (e.g. social areas with furniture within multi-family development, social shared spaces within the same development, etc.)	0.33
		Area intended for food production (e.g. communal garden)	0.44
		Non-accessible vegetated area, visible from public pedestrian area (not intended for activity (e.g. ornamental garden)	0.11
		Area intended to exclusively provide insect / animal shelter	0.11
	Public access / use	Donation of private area or shade for public use (donated surface area + tree canopy area in public space)	0.33
	Soil connection	Connected soil	0.22
		Unconnected - Deep soil (incl. Intensive green roof)	0.07
		Unconnected - Shallow soil (incl. Extensive green roof)	0.04
	Vegetation water demand	Vegetation - drought tolerant species (e.g. xerophytes, etc.) - minimal irrigation	0.33
		Vegetation - high efficiency irrigation with recycled/treated water	0.22
		Vegetation - standard irrigation with recycled water	0.11
		Vegetation - high efficiency irrigation with potable water	0.00
		Vegetation - standard irrigation with potable water	0.00
	Preserved trees	Vegetation - Trees - Preserved	0.22
	Reflective Surface	Surface with high SRI (e.g. white roof)	0.11

Table 16. Environmental Performance Assessment

					CULTURAL		PROVISIONING			REGULATING				SUPPORTING		
					Aesthetics / Visual Interest	**Social cohesion and recreation**	**Clean energy**	**Urban agriculture / Food provision**	**Water saving**	**Flood risk reduction**	**Cleaner air**	**Noise reduction**	**Thermal regulation**	**Diversity**	**Insect / Animal habitat**	**Undisturbed nature**
					ECOSYSTEM SERVICE WEIGHTINGS											
PRACTICE GROUP	PRACTICE TYPE	**PRACTICE**	**FINAL WEIGHTING**	COMBINED WEIGHTING	1	3	1	1	3	1	1	1	3	1	1	1
Surface System	Permeable	Bare soil	**0.70**	19	**2**		**0**		**3**	**3**			**1**		**2**	
		Gravel	**0.63**	17	**2**		**0**		**3**	**3**			**1**		**0**	
		Green wall	**0.33**	9	**3**		**0**		**1**	**0**			**0**		**3**	
		Groundcovers	**0.67**	18	**3**		**0**		**1**	**3**			**2**		**3**	
		Lawn	**0.56**	15	**3**		**0**		**0**	**3**			**2**		**3**	
		Mulch	**0.70**	19	**2**		**0**		**3**	**3**			**1**		**2**	
		Sand	**0.70**	19	**2**		**0**		**3**	**3**			**1**		**2**	
	Semipermeable	Combined green/gray surface (e.g. block grass, grass grid, etc.)	**0.41**	11	**2**		**0**		**1**	**2**			**1**		**1**	
		Permeable paver (preferably unbound)	**0.52**	14	**0**		**0**		**3**	**2**			**1**		**0**	
	Impermeable	Artificial turf	**0.41**	11	**2**		**0**		**3**	**0**			**0**		**0**	
		Asphalt	**0.33**	9	**0**		**0**		**3**	**0**			**0**		**0**	
		Concrete	**0.33**	9	**0**		**0**		**3**	**0**			**0**		**0**	
		Impermeable paver (bound)	**0.33**	9	**0**		**0**		**3**	**0**			**0**		**0**	
		Red terracotta tile	**0.33**	9	**0**		**0**		**3**	**0**			**0**		**0**	
		Solar PV	**0.56**	15	**0**		**3**		**3**	**0**			**1**		**0**	
		Wooden deck	**0.52**	14	**2**		**0**		**3**	**0**			**1**		**0**	
	Water Bodies	Water features (incl. fountains, water mirrors, ponds etc)	**0.52**	14	**3**		**0**		**0**	**0**			**3**		**2**	
		Wetland (as water treatment plant)	**1.00**	27	**3**		**0**		**3**	**3**			**3**		**3**	
Vegetation Unit		Tree	**0.78**	21	**3**		**0**		**1**	**3**			**3**		**3**	
		Shrub	**0.67**	18	**3**		**0**		**1**	**3**			**2**		**3**	
Shading Unit	Shading measure / structure	Shading structure	**0.48**	13	**1**		**0**		**3**	**0**			**1**		**0**	
		Shading structure with vegetation	**0.48**	13	**3**		**0**		**1**	**0**			**2**		**1**	
		Shading structure with solar PV	**0.70**	19	**1**		**3**		**3**	**0**			**2**		**0**	
Functional Surface	***Intended use***	Area intended for recreation in donated public/semi-private spaces (e.g. playground, sports areas within donated public spaces or multifamilar shared spaces, etc.)	**0.33**	9		**3**		**0**							**0**	
		Area intended for social interaction in donated public/semi-private spaces (e.g. social areas with furniture within multifamiliar development, social shared spaces within the same development, etc.)	**0.33**	9		**3**		**0**							**0**	
		Area intended for food production (e.g. communal garden)	**0.44**	12		**3**		**3**							**0**	
		Non-accessible vegetated area, visible from public pedestrian area (not intended for activity) (e.g. ornamental garden)	**0.11**	3		**1**		**0**							**0**	
		Area intended to exclusively provide insect / animal shelter	**0.11**	3		**0**		**0**							**3**	
	Public access / use	Donation of private area or shade for public use (donated surface area + tree canopy area in public space)	**0.33**	9		**3**										
	Soil connection	Connected soil	**0.22**	6						**3**			**0**		**3**	
		Unconnected - Deep soil (incl. Intensive green roof)	**0.07**	2						**0**			**0**		**2**	
		Unconnected - Shallow soil (incl. Extensive green roof)	**0.04**	1						**0**			**0**		**1**	
	Vegetation water demand	Vegetation - drought tolerant species (e.g. xerophytes, etc.) - minimal irrigation	**0.33**	9					**3**							
		Vegetation - high efficiency irrigation with recycled/treated water	**0.22**	6					**2**							
		Vegetation - standard irrigation with recycled water	**0.11**	3					**1**							
		Vegetation - high efficiency irrigation with potable water	**0.00**	0					**0**							
		Vegetation - standard irrigation with potable water	**0.00**	0					**0**							
	Preserved trees	Vegetation - Trees - Preserved	**0.22**	6									**1**			**3**
	Reflective Surface	Surface with high SRI (e.g. white roof)	**0.11**	3									**1**			

Table 17. Asessment criteria and scale used for each ES in the Environmental Performance Assessment

ES	Assessment criteria	Scale used
Flood risk reduction	The capacity of a practice to support on the retention, detention, infiltration and drainage of stormwater and river flooding	Based on Keeley´s approach (2011), 'Permeable surfaces', 'Tree', 'Shrubs' and 'Connected soils' received the highest score (3 points), followed by 'Semi-permeable surfaces', which received 2 points. The lowest score was attributed to 'Green Walls' and all 'Impermeable surface', 'Water features' and 'Shading measures', as well as, to 'Unconnected soils'.
Thermal regulation	The capacity of a practice to perform as an Urban Heat Island (UHI) mitigation strategy by either cooling or producing a minimal warming effect in air temperature over the area where they implemented.	Refer section 5.2.3.1
Undisturbed nature	The capacity of a practice to encourage the preservation of existing trees.	Establishing to what extent a practice can protect or disturb existing vegetation through its physical attributes (surfaces) in these senses may demand profound research and it is out of the scope of this work. Notwithstanding, avoiding disturbances can be considered, as a starting point, as a 'Functional Surface'. Therefore, the use of native species is not assessed, but it was rather established as a suggestion of high consideration. On the other hand, 3 points were given to the practice 'Vegetation - Trees – Preserved' to boost the weighting of a 'Vegetation Unit' that includes this consideration in the project.
Insect/Animal habitat	The capacity of a practice to host animal and insect habitat (biotopes).	All practices based on vegetation that are likely to be in deep or connected soil received 3 points as well as 'Wetland'. Two points were granted to 'Surfaces' that are composed of natural materials (including water in the case of 'Fountain') and support vegetation. One point was given to 'Semipermeable' surfaces that included vegetation partially. All 'Impermeable Surfaces' and those not supporting vegetation received the lowest score (0 points). Vegetation growth can be limited by the soil depth. Therefore, additional scores were given in 'Soil Connection' to boost practices' weightings according to the soil condition they considered. Consequently, 'Connected to soil' received the highest score (3 points) and deep and shallow soils 2 and 1 points, respectively. Finally, previous analyses suggested the inclusion of habitat units (e.g. animal shelters) within the landscaping projects. Therefore, 3 points were added to projects that present this consideration.

Table 17. Asessment criteria and scale used for each ES in the Environmental Performance Assessment		
ES	**Assessment criteria**	**Scale used**
Urban agriculture / Food provision	The capacity of a practice to host agriculture activities at an urban scale.	Areas intended for the development of this practice received 3 points, as they have considered the adequate spatial requirements for this activity to take place. A specific 'intended use' was included to this end.
Water saving	The capacity of a practice to guarantee limited water resources are needed and reduce dependency on potable water.	Areas using drought tolerant vegetation and using minimal vegetation received 3 points. For other types of vegetation, if high efficiency irrigation with treated water is used, it received 2 points, while standard irrigation with recycled water received 1 point. Any irrigation method using potable water received zero points. 'Surface systems' and 'Shading structures' without vegetation which do not require water for maintenance were assigned 3 points. 'Groundcover', 'Green wall', 'Combined green/grey surface', 'Tree' and 'Shrub' were given 1 point, while ''Lawn' was given 0 points, as it typically is water intensive. 'Wetland' was given 3 points as it facilitates water storage and treatment. 'Fountain' received 0 points as they often require replenishment due to evaporations.
Clean energy	The capacity of a practice to generate clean energy during its lifetime.	3 points were given to surfaces that include solar panels on roof surfaces or on shading structures.
Aesthetic / Visual interest	The capacity of a practice to contribute to the increase of the attractiveness of the urban environment, through the increase of the quantity of natural ornamental elements in the landscape, while delivering positive emotions and sensorial experiences.	Based on the classification framework developed by Kellert and Calabrese (2015) only physical attributes were considered (i.e. no Functional Surfaces). The highest scores were given to vegetated surfaces and water as they provide direct experience with nature (3 points). Practices with minimal vegetation, made of natural materials, ornamental features or mimicking (evoking) nature such as artificial turf and water features received 2 points. Shading structures deliver comfort and protection from extreme warm temperatures. Therefore, all were granted with 1 point, but the one with vegetation received 3 additional. Other practices may also have aesthetic values, but this may be subjected to the preference in the design, hence they received 0 points.

Table 17. Asessment criteria and scale used for each ES in the Environmental Performance Assessment

ES	Assessment criteria	Scale used
Social cohesion and recreation	The capacity of a practice to host social and facilitate leisure activities (individual or collective) with amenities for human interaction	Weightings were given only to practices within the 'Functional Surface' section. This means that these attributes can be incorporated as a layer over surfaces. The highest score (3 points) was given to practices that promote either recreation or social activities or urban agriculture within a surface at the time. Inaccessible vegetated areas that are exclusively ornamental, or solely to look at, received only 1 point, as they contribute to access to nature but with significant visitor limitations. Additionally, 3 points were assigned to 'Donation of private area or shade for public use (donated surface area + tree canopy area in public space)' as it facilitates social activities within its space.
Ecosystem services not assessed		
Noise reduction	The capacity of a practice to reduce noise.	Given the limited information about its relevance in Lima, in addition to the site-specific requirements for practices to be effective, no practice was assessed against this ES.
Reduced air pollution	The capacity of a practice to reduce air pollution.	Given the high number or variables and potential for detrimental effects if not considered, no practice was assessed against this ES.
Diversity	The capacity of a practice to increase biodiversity.	Given the limited information and its low relevance for Lima, no further assumptions were executed. Hence, it was determined not to assess any practice against this ES

5.2.3.1. PRACTICE WEIGHTINGS FOR THERMAL REGULATION

Thirty scenarios were modelled with ENVI-met 4.4.5 to simulate the effect in air temperature above the area where the surface material of each practice was implemented. The full list of scenarios is presented in **Appendix 6** while the material properties are shown in **Appendix 7**. A matrix showing how the scenarios were compared is in **Appendix 8**.

SURFACE SYSTEMS

The final scores for 'Surface Systems' were assigned as shown in Table 18. The scores were determined based on analysis of 'Surface Systems' applied at street level, with exception of the following, which were scored based on available literature:

- 'Gravel', 'Mulch', 'Artificial turf' and 'Solar PV', for which material properties were not readily available in ENVI-met
- 'Green wall', which was applied only to walls

Table 18. Scores assigned to 'Surface Systems'

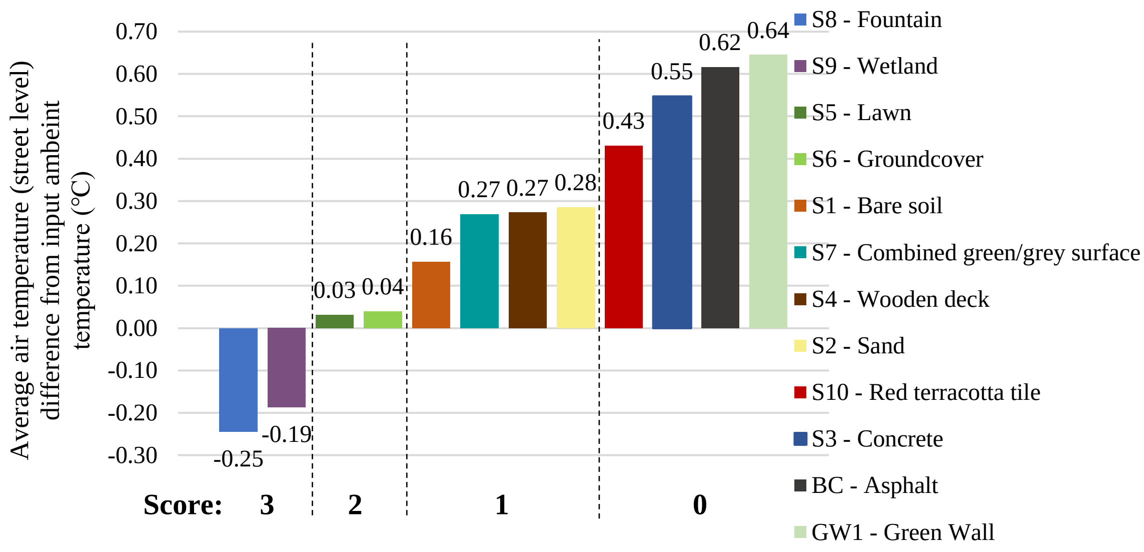
Score	Practice	Rationale
3	Fountain	ENVI-met analysis
	Wetland	ENVI-met analysis
2	Groundcover	ENVI-met analysis
	Lawn	ENVI-met analysis
1	Bare soil	ENVI-met analysis
	Combined green/grey surface	ENVI-met analysis
	Gravel	'Gravel' can be considered as a permeable surface. Considering that hard surfaces can store more heat and their heat loss rate is also higher than permeable ones (Osmond and Sharifi, 2017), 'Gravel was then given the same score as 'Sand' and 'Bare Soil'. Namely, it was considered as thermally detrimental as hard surfaces, particularly as in this case the typical light-coloured surface of 'Gravel' may have a cooling effect, from an albedo perspective.
	Mulch	Mulch often has a dark colour (low albedo), as for instance 'Asphalt'. However, like 'Gravel', it is permeable. In addition, its ability to retain moisture in the soil may potentially decrease its capacity to gain heat. It was therefore given the same weighting as 'Gravel'.
	Permeable paver (preferably unbound)	ENVI-met analysis (assumed to be same as 'Combined green/grey surface')
	Sand	ENVI-met analysis
	Solar PV	Solar PV has a low albedo. However, it is designed to absorb solar radiation and convert it into energy, rather than storing the energy as heat and releasing it later, like other dark surfaces. Therefore, it

		will not perform exactly as a dark surface and it will be highly likely to remain cool. Further, panels with a ventilated air gap with the roof cool the roof surface (Wang et al, 2006). Therefore, 1 point was given as it will not perform as efficiently as vegetation, nor as detrimental as hard dark surfaces.
	Wooden deck	ENVI-met analysis
0	Artificial turf	While artificial turf may have the same albedo as lawn, it is unable to provide natural cooling via evapotranspiration. It was therefore given a weighting of zero.
	Asphalt	ENVI-met analysis
	Concrete	ENVI-met analysis
	Green Wall	ENVI-met analysis
	Impermeable paver (bound)	ENVI-met analysis (assumed to be same as 'Concrete')
	Red terracotta tile	ENVI-met analysis

The air temperature at street level (2.5m) was measured at each hour for each 'Surface System' applied to streets (and walls in the case of 'Green Wall'). It was then compared to the ambient air temperature. The average difference between the measured air temperature and the ambient temperature across 24 hours is shown in Figure 13. A negative value means the temperature was cooler than the ambient temperature. This shows the 'Surface Systems' can be divided in four groups. On average:

- 'Fountain' and 'Wetland' have a cooling effect
- 'Lawn' and 'Groundcover' have negligible effect
- 'Bare soil', 'Combined green/grey surface', 'Wooden deck' and 'Sand' have a mild warming effect
- 'Red terracotta tile', 'Concrete', 'Asphalt' and 'Green Wall' have a moderate warming effect

Figure 13. 'Surface systems' applied at street level (average difference in air temperature at street level from ambient temperature across 24 hrs)



These groupings remained consistent at the different times observed, except at 12pm when 'Red terracotta tile' was cooler than 'Sand', as shown in Figure 14. Nevertheless, it was decided to group it together with the other non-permeable 'Surface Systems' ('Asphalt', 'Concrete'). Figure 15 shows the air temperature at each hour.

Figure 14. 'Surface Systems' applied at street level (difference in air temperature at street level from ambient temperature– 12:00, 16:00, 20:00)

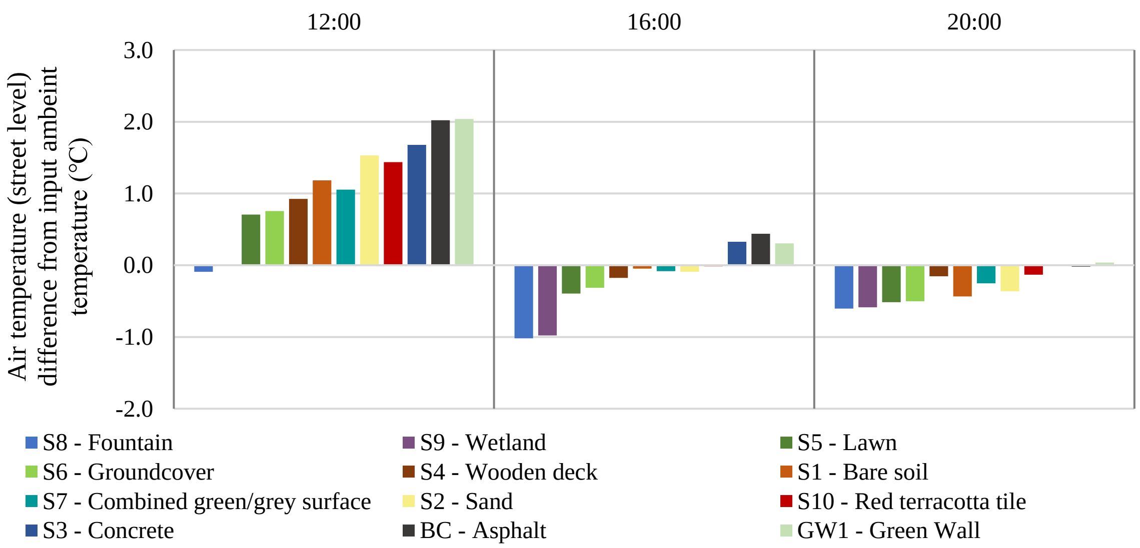
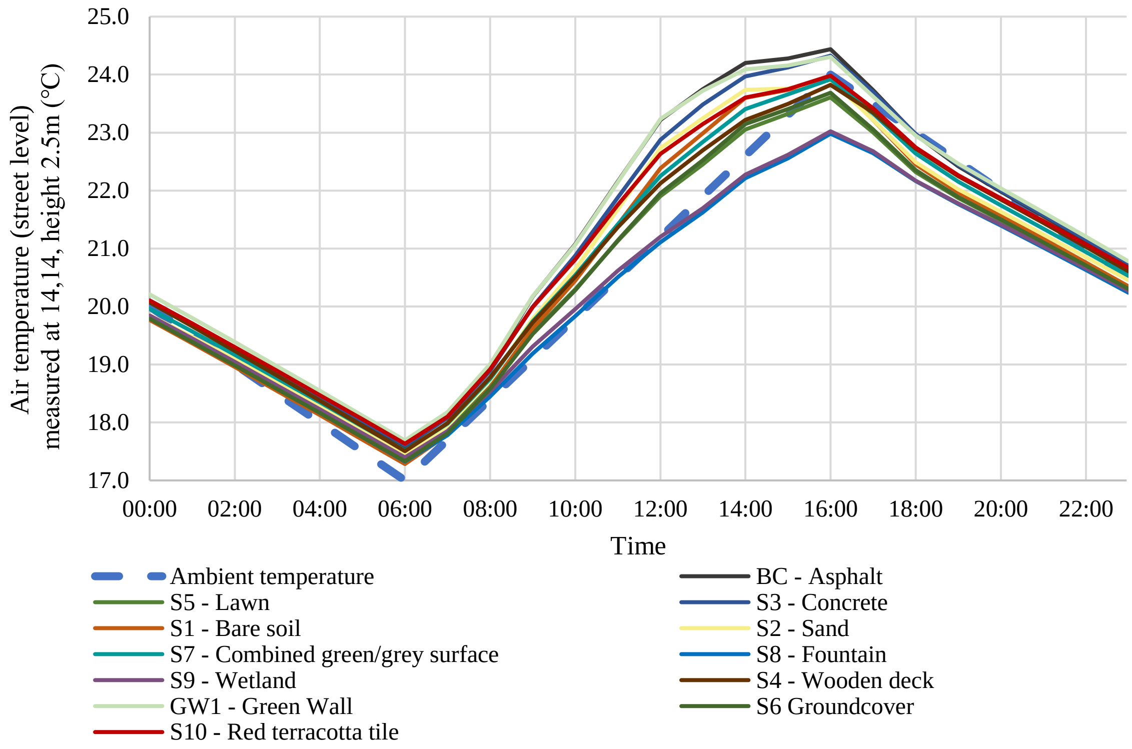


Figure 15. 'Surface Systems' applied at street level – air temperature at street level



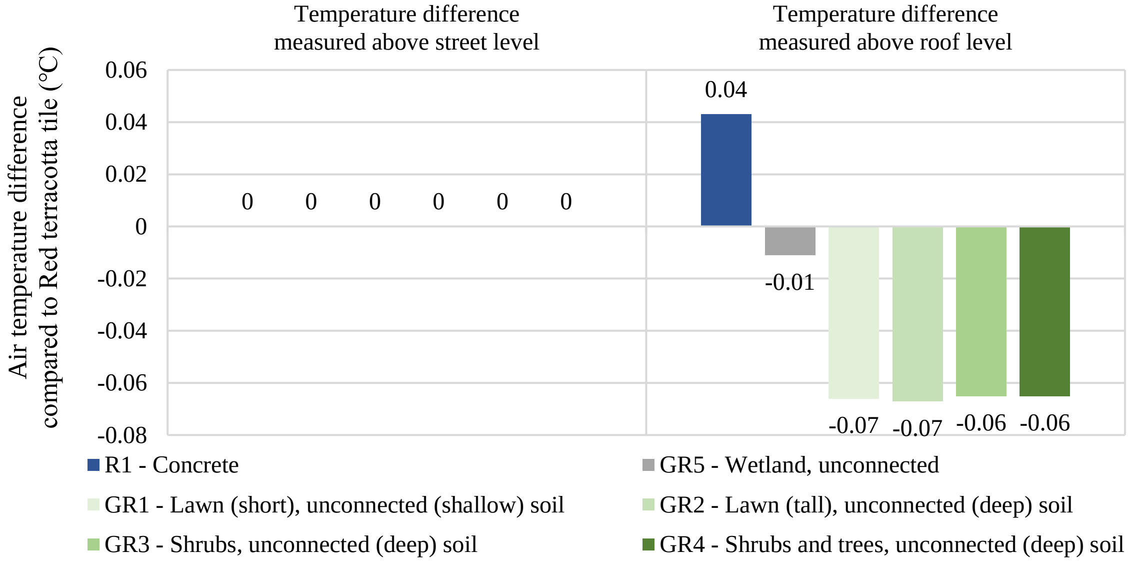
Application of 'Surface Systems' to building roofs

Relevant 'Surface Systems' were also applied to roofs, to determine whether there was any effect on air temperature at either the street or above roof level from changing the 'Red terracotta tile' in the BC to common local roofing surfaces, such as 'Concrete', and green roofs (extensive and intensive).

The results, shown in Figure 16 (left side), revealed the impact on air temperature at the street level (2.5m) from changing roof surfaces was negligible.

In contrast, small differences were observed in air temperature measured above roof level (17.5m). 'Concrete' was slightly warmer than the base case 'Red terracotta tile', while green roofs were slightly cooler during the middle of the day (Figure 16 – right side). However, the maximum cooling effect was only 0.07°C. This is much smaller than the temperature variations observed when 'Surface Systems' were applied at the street level (shown in Figure 14 – for instance, the difference between 'Red terracotta tile' and 'Lawn' at 12pm was 0.73°C). Therefore, no scoring differentiation was made for 'Surface Systems' applied at the roof level versus at the ground level.

Figure 16. ‘Surface Systems’ applied to building roofs (difference in air temperature at street and roof levels compared to ‘Red terracotta tile’ – 12:00)



VEGETATION UNITS

Weightings for ‘Vegetation Units’, shown in Table 19, were determined by comparing scenarios of ‘Surface Systems’ with and without these units, applied at street level. The addition of trees and shrubs resulted in lower air temperatures in all scenarios.

Table 19. Scores assigned to ‘Vegetation Units’ and ‘Functional Surface – Preserved trees’

Practice Group	Score	Practice	Rationale
Vegetation Unit	3	Tree	ENVI-met analysis
	2	Shrub	ENVI-met analysis
Functional Surface	1	Vegetation – Trees – Preserved	To account for the immediate benefit provided by existing trees, while new trees require time to reach maturity and provide maximum benefit.

Figure 17 shows the difference between the average air temperature at street level of the ‘Surface System’ without trees and with trees. It shows that the reduction in temperature after applying trees is between 0.44°C and 0.58°C for each ‘Surface System’. This is approximately double the effect of the ‘Fountain’ (alone) on ambient air temperature (0.25°C reduction). The temperature reduction resulting from ‘Shrub’ was less than for ‘Trees’, but nevertheless significant, as shown in Figure 18.

Therefore, ‘Tree’ was assigned a weighting of 3 (the same weighting as ‘Fountain’) and ‘Shrub’ was assigned 2 points (the same value as for ‘Lawn’ and ‘Groundcover’).

Figure 17. 'Surface Systems' - comparison of average air temperature difference at street level across 24 hrs resulting from trees

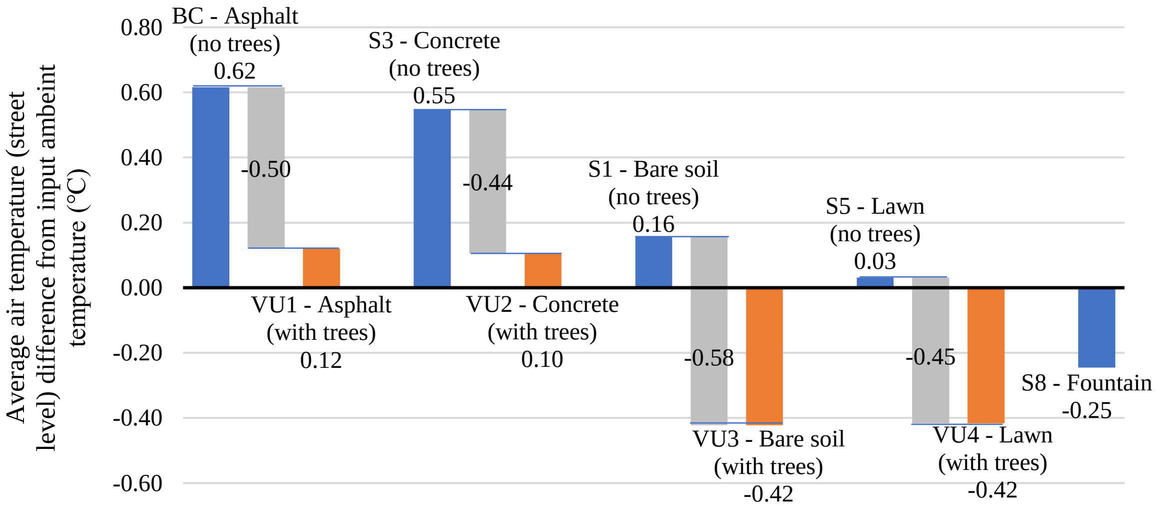
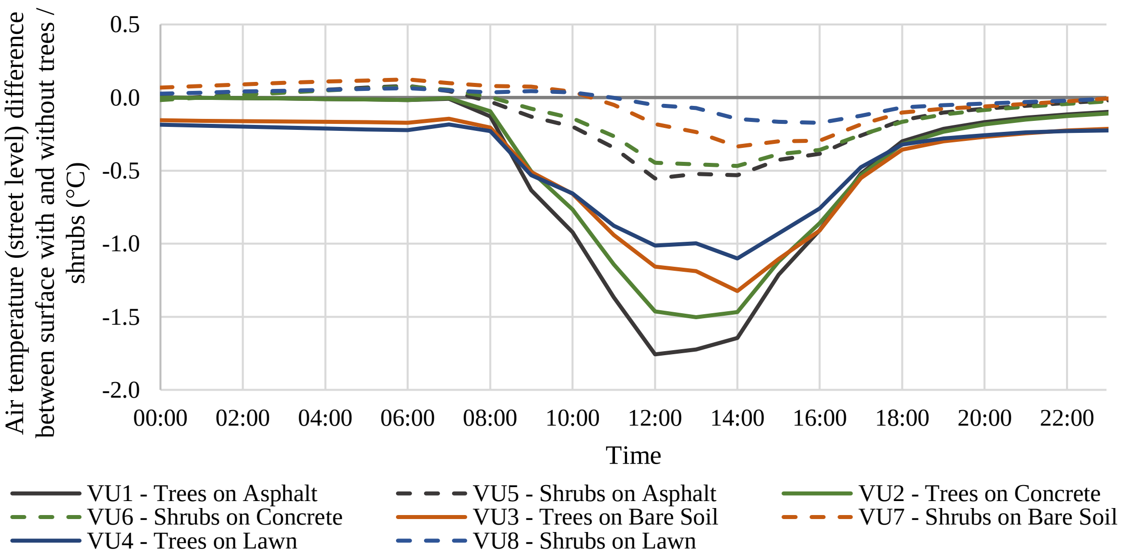


Figure 18. Comparison of impact of 'Trees' and 'Shrubs' on selected 'Surface Systems' – air temperature at street level



SHADING UNITS

'Shading Units' were unable to be modelled in ENVI-met. However, the ENVI-met results for 'Trees' demonstrate the positive benefits to thermal regulation that can be provided by shade, as many studies indicated (section 2.2.2). The scores assigned for 'Shading Units' are explained in Table 20.

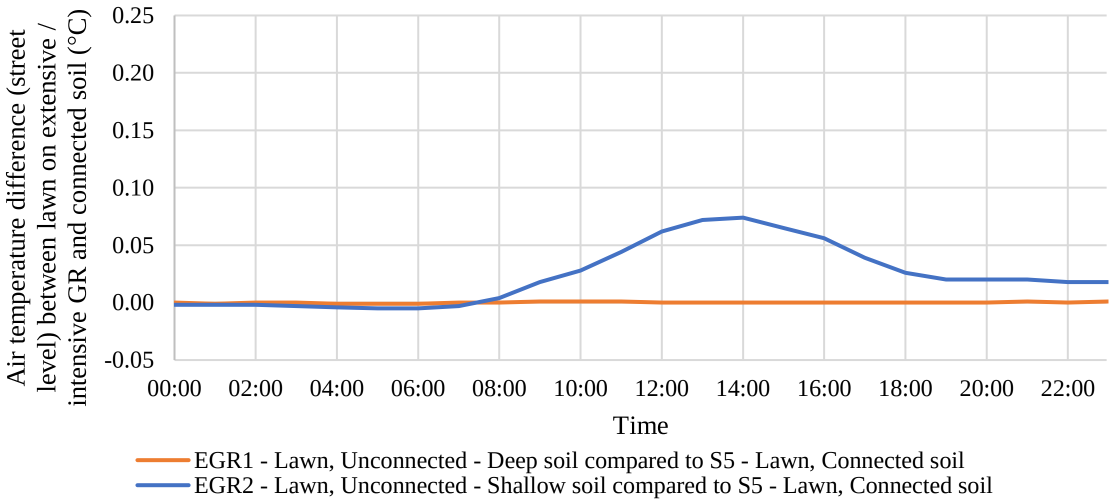
Table 20. Scores assigned to 'Shading Units'

Practice group	Score	Practice	Rationale
Shading unit	2	Shading structure with vegetation	A structure using vegetation to provide shade may be likely to perform as a 'Tree', however it will depend on the nature of the vegetation added (e.g. density of leaves). It is therefore assumed that the cooling effect will be less than a 'Tree', so the practice is given a weighting of 2.
	1	Shading structure (without vegetation)	A 'Shading structure' without vegetation (e.g. pergolas, shade sails, verandas) will have a similar shading effect as a tree or shading structure with vegetation. However, they lack the additional cooling potential from the vegetation (e.g. due to evapotranspiration) and the materials of the structure may absorb more heat. Therefore, it is given a weighting of 1.
	2	Shading structure with solar PV	As a 'Surface System', 'Solar PV' received 1 point. To reflect the additional benefit of shading, 'Shading structure with solar PV' was given a weighting of 2.

SOIL CONNECTION

The influence of soil depth was modelled to determine whether surfaces on shallow soil (e.g. extensive green roofs) perform differently to those on deeper or connected soil. The surfaces were applied at the street (ground) level to simulate vegetated areas on top of subterranean structures (e.g. basement carparks). The air temperature difference at street level of an intensive green roof (1m depth) was negligible compared to 'Lawn' on 'Connected soil'. The extensive green roof (20cm) was warmer than 'Lawn' on 'Connected soil', but only by a maximum of 0.074°C (as shown in Figure 19). This was not considered a large enough impact to warrant assigning points to the 'Soil Connection' within 'Functional Surfaces'.

Figure 19. Air temperature (street level) difference between 'Lawn' on unconnected (shallow / deep) soil compared to connected soil



SURFACE REFLECTIVITY

The weighting for the 'Reflective Surface', 'Functional Surface' is, shown in Table 21. This was determined by comparing high albedo ('white-painted') versions of 'Asphalt' and 'Concrete' ('Surface Systems') streets against the originals (considered to be the most common candidates for conversion to high albedo surfaces).

Table 21. Scores assigned to 'Functional Surface – Reflective Surface'

Practice group	Score	Practice	Rationale
Functional Surface	1	Surface with high SRI (e.g. white roof)	ENVI-met analysis

Figure 20 shows for the high reflectivity surfaces, the air temperature at street level is cooler than the original materials, and approximately the same temperature as 'Lawn' between 8am and 4pm. However, over the course of the day, the average air temperature reductions were more closely aligned to those achieved by 'Combined green/grey surface' and 'Wooden deck'. This was therefore equivalent to an increase in weighting of 'Asphalt' and 'Concrete' from 0 to 1, and therefore 'Surface reflectivity' was given a weighting of 1.

Figure 20. 'Surface Systems' with increased reflectivity applied at street level – air temperature at street level ('Lawn' included for comparison)

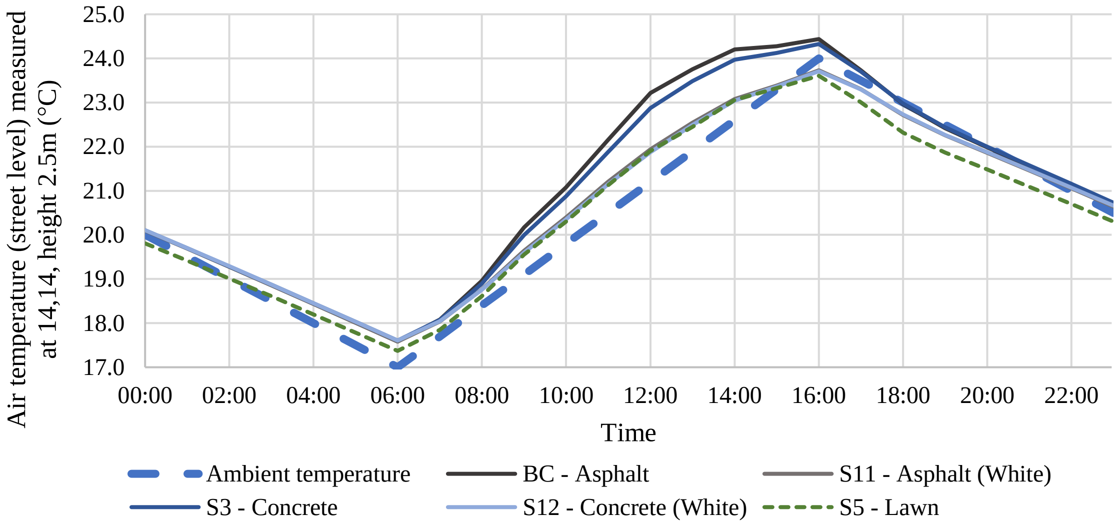
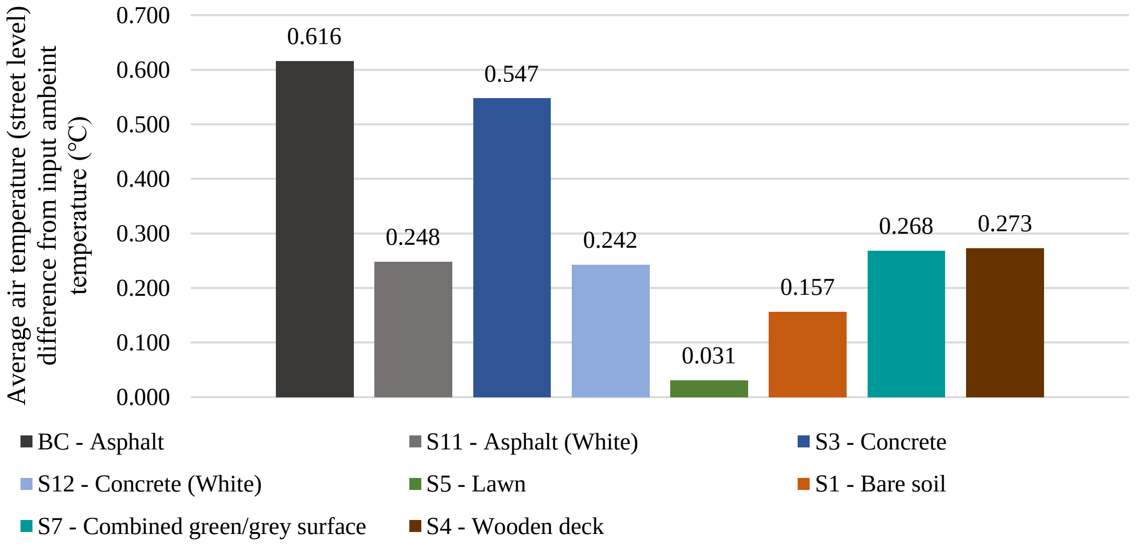


Figure 21. 'Surface systems' with increased reflectivity applied at street level (average difference in air temperature at street level from ambient temperature across 24 hrs) – other 'Surface Systems' included for comparison



5.3. APPLICATION OF THE TOOL

The GAR Lima- Score achieved by the three projects is shown in Table 22. The GAR calculation sheet of each case is presented in **Appendix 9**.

Table 22. GAR Lima - Scores achieved by local buildings

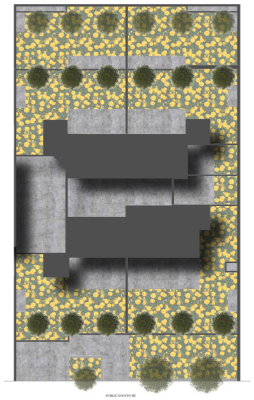
Project	Plot size (m2)	% plot area vegetated	Condition	GAR Lima-Score
Olavide	359.5	50.1%	Sustainable	0.47
Palas	2574.39	12.7%	Sustainable	0.47
Huaylas	4881.5	38.5%	Traditional	0.50

The results show all three projects having a similar GAR Lima-Score. This is despite of 'Olavide' and 'Palas' being developed under sustainable design building measures and 'Olavide' having a much higher proportion of vegetated area compared to the other two projects.

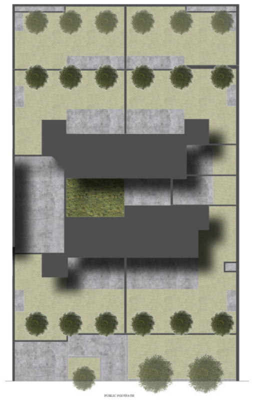
With regard to the retrofit scenarios developed for 'Olavide', all the 'water sensitive' scenarios (Figure 22) received a higher GAR Lima-Score than the Base Case (BC). This included all 'Xeriscape' scenarios. All of the 'non-water sensitive' scenarios (Figure 23) also scored higher than the BC. Some featured additions such as trees, shading structures or solar panels. The two 'neglected' green roof cases also received slightly higher GAR-Scores as both 'Bare soil' and 'Gravel' have higher 'Final weightings' than 'Lawn'. The three 'alternative surfaces' all scored lower than the BC.

The score calculations for each of the 17 retrofit scenarios developed for 'Olavide' are shown in **Appendix 10**.

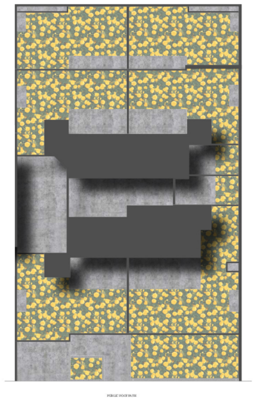
Figure 22. Water sensitive scenarios



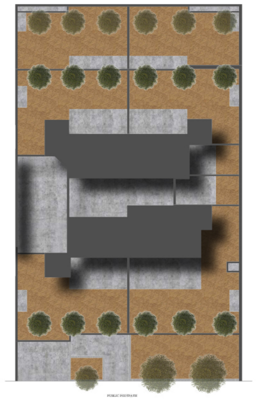
X1
Xeriscape intensive (drought tolerant groundcover + trees)
0.84



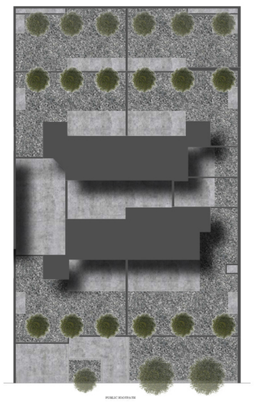
G1
Lawn intensive (BC) + high efficiency irrigation using treated grey water + wetland (wtp) + trees
0.73



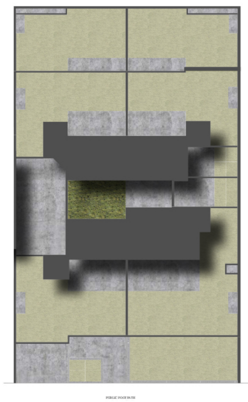
X2
Xeriscape extensive (drought tolerant groundcover)
0.69



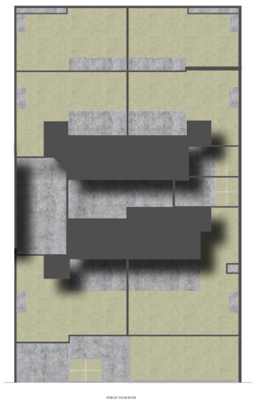
X3
Xericape intensive (bare soil + trees drought tolerant)
0.69



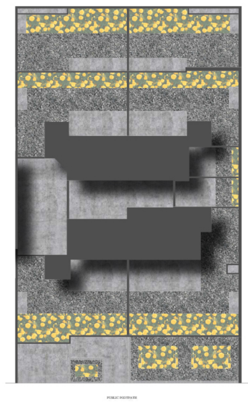
X4
Xeriscape intensive (gravel + drought tolerant trees)
0.65



G2
Lawn extensive (BC) + high efficiency irrigation using treated grey water + wetland (wtp)
0.60

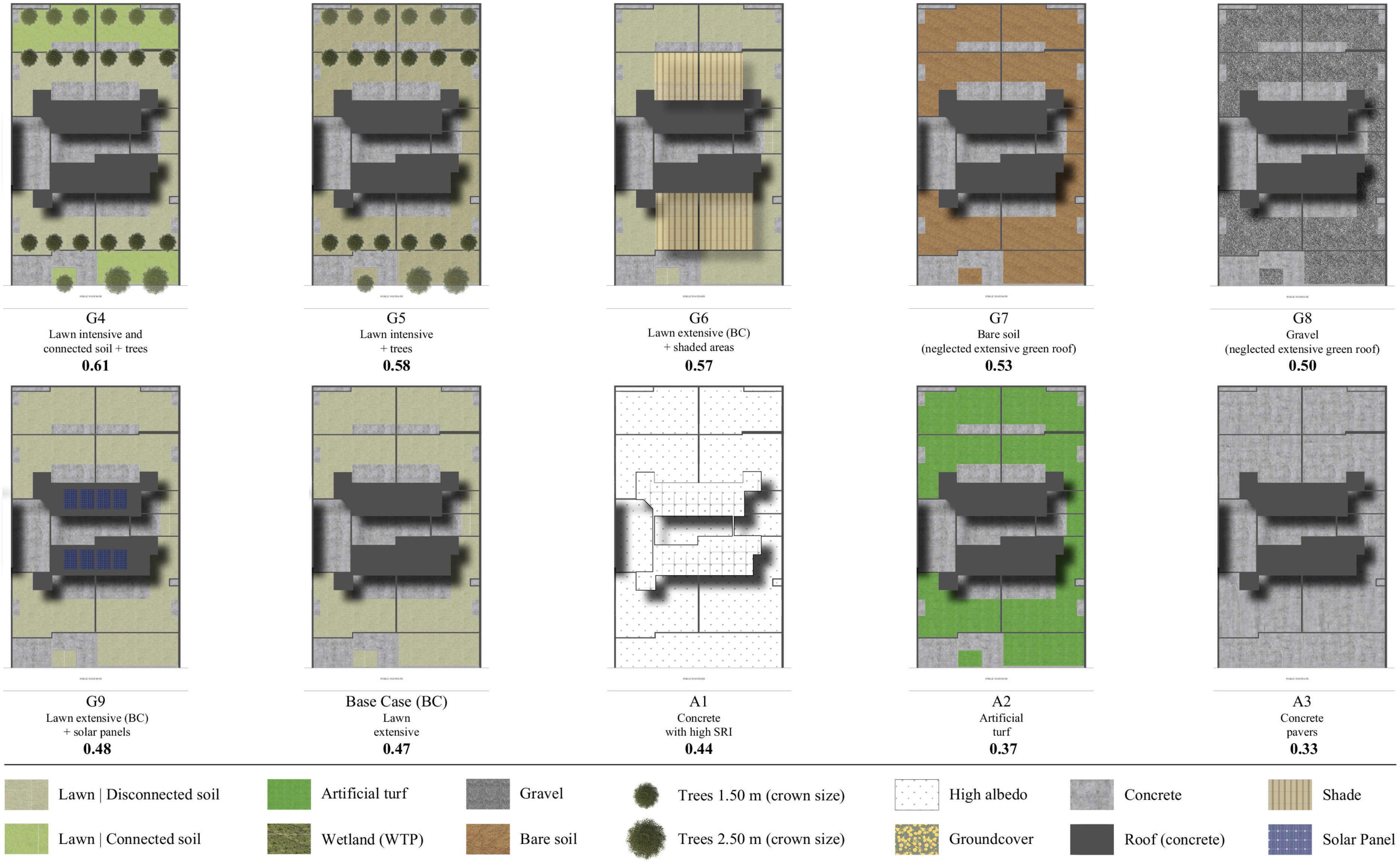


G3
Lawn extensive (BC) + high efficiency irrigation using treated grey water
0.58



X5
Xeriscape extensive (gravel + drought tolerant groundcover)
0.57

Figure 23. Non-water sensitive scenarios and alternative surfaces



6. DISCUSSION

6.1. A SUITABLE GAR TOOL

6.1.1. THE NEED FOR ADAPTATION

The results suggested that no existing GAR tool could adequately guide Lima in the implementation of GI with high sensitivity to water conservation and thermal regulation. The main reason could be that none of the nine existing tools was developed for an arid context like Lima. This could have been a reason for the nine cities to have different approaches towards GI's implementation as a measure for thermal regulation and water conservation.

For instance, the way that the nine cities intended to mitigate UHIs and the approach of their 'Practices' based on improved irrigation was very aligned to the local level of rainfall. Table 11 shows water conservation was addressed through 'Practices' that included the cultivation of drought-tolerant species and irrigation principally with harvested stormwater, while cooling purposes were pursued through the implementation of water features. However, except for drought-tolerant species, Lima's local guidelines considered principally the implementation of domestic grey water treatment plants for irrigation and recommended reflective coatings to improve thermal regulation.

There were also further relevant differences between Lima and the other cities, especially between the socio-cultural urban context. In both groups, the GAR tools and Lima's local guidelines, social activities and common areas were linked to leisure. However, the accessibility of green areas within street/pedestrian and ground floors was not mentioned in existing GAR tools. Lima intends to increase the access to leisure in green spaces without restrictions due to maintenance, by rewarding the donation and conversion of private areas into public spaces.

These significant differences were considered sufficient to conclude that the direct application of any of the nine GAR tools in Lima may mislead the achievement of ESs, especially related to water conservation ('Water saving') and 'Thermal regulation'. Therefore, none may adequately weigh or reward all 'Practices' that could result important and suitable for a densely built arid context like Lima - for instance, high-albedo surfaces for 'Thermal regulation', since it is not vegetated and does not demand water.

If a development in Lima is designed in such a way that it achieves a high GAR-Score under any of the nine GAR tools, it would be reflecting a high ecological value for a different context to Lima's. It would, therefore, guide the implementation of GI in a way that may not be necessarily beneficial or sustainable, making the GAR tool to ineffective if applied outside its context of origin, unless the local context is highly similar climatically and culturally.

Therefore, the BAF-Score calculated by Miranda et al. (2015) for the project ‘Palas’ (Table 8) may not properly reflect the ecological functionality and contribution of the project’s green areas and other surfaces within the Lima context. Certain valuable UHI mitigation measures (shaded areas with structures and trees) and other relevant ‘Practices’ for Lima, such as open common leisure areas and concrete surfaces covered by solar panels were not accounted for. Since the BAF did not consider ‘Water Saving’ as part of its set of ESs, Palas’s GI may not be ‘ecologically functional’ in terms of water conservation (ES ‘Water saving’), setting the project’s green areas in risk of not being sustainable and potentially causing disservices during project’s lifecycle.

Despite the GAR-tool being considered a metric for sustainability by Keeley (2011) and other authors, the fact that no previous experiences with the GAR tool in arid contexts were found suggests the creation of a tool for Lima is a novel approach for the arid context. An existing tool would require, therefore, adaptation and further testing to conclude whether it may be a suitable to guide Lima and similar contexts in how to increase the ratio of green areas in a sustainable way. Therefore, the creation of a new version demanded significant variations in the calculation system, which will be discussed later.

6.1.2. A SUSTAINABLE METRIC

The approach of most of the existing GAR tools towards ‘Water saving’ and ‘Thermal regulation’ can be considered resilient and sustainable within their own contexts. The inclusion of the ES ‘Flood Risk Reduction’ with high ‘Final weightings’ attributed to permeable surfaces in almost all cases (Table 7) – as well as using rainwater for cooling purposes – reveal cities’ concern for achieving resilience against flooding and temperature raise. Due to climate change, a variability of rainfall patterns and temperature is expected in Europe and the United States, which will lead to severe flooding events, as well as droughts and heat waves. Moreover, the global demand for water is expected to exceed viable resources by 40% by 2030 under a business as usual scenario (WWAP, 2015). Therefore, despite there being a natural availability of rainfall that is important for vegetation maintenance, ‘Practices’ based on detention and filtering, but principally, harvesting stormwater, are key to warrant water security and conservation as well as to deliver urban resilience and strengthen local circularity in water use. Such kind of ‘Practices’ decreases stress on water demand for irrigation, facilitates the recharge of aquifers, whilst reducing the cost of damages caused by floods and improving wastewater treatments (Gleason Espíndola et al, 2018). The use of harvested stormwater in water features for cooling purposes is in that sense valid if it does not increase stress on other resources like energy. Stormwater harvesting could also represent an opportunity for arid environments with seasonal rainfall events as long as its quantity can be sufficient to support irrigation during the drought period. However, in Lima, with extremely low rainfall, stormwater management is not a high priority.

6.1.3. UNCERTAINTIES AS A PLANNING TOOL

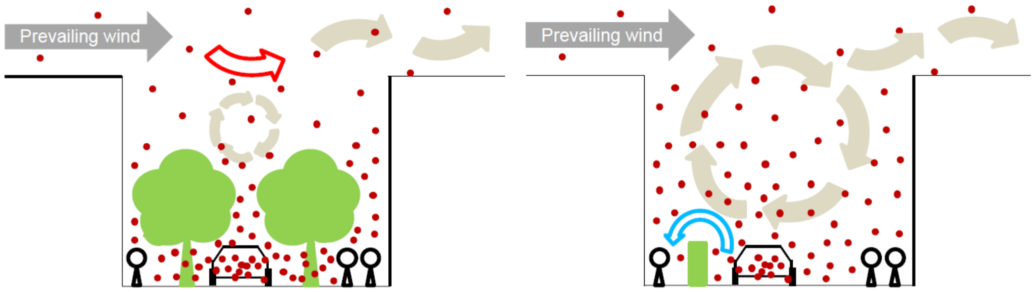
GAR calculators mostly, provided very general or little detail about the definition of their 'Practices' and how this work: e.g. 'vegetation contributes to air quality'. This could be intentional since the presence of fewer variables may facilitate decision-making. For instance, Edwards (2014) indicates that tools for sustainability, such as LEED and BREEAM, are based on readily understood principles represented as indicators, which provide a practical guide to the bigger picture and has resulted well accepted in the planning and building sector.

In the case of most existing GAR tools, in order to be user friendly and achieve simplicity, such 'readily understood principles' included one variation of each 'Practice' – e.g. Asphalt, Tree, Lawn etc, generalising its attributes. The scenario where the 'Practice' is implemented and assumes the performance of the 'Practice' is exactly the same in each instance. For example, most calculators did not differentiate physical characteristics (colour, material etc), nor factors such as usage, spatial arrangement or climate, which can significantly impact in the achievement of certain ESs.

This represents a potential risk. Generalisations and the omission of some parameters may make the measurement of the impact of the delivery of ESs by certain 'Practices' less accurate. In Table 17 and **Appendix 5** (section 'Ecosystem services not assessed'), it can be observed that the revised literature indicated the delivery of some ESs is highly dependent on external conditions (e.g. wind direction, surrounding physical conditions, urban morphology) and sometimes goes beyond just the physical attributes intrinsic of the 'Practice'. If such external conditions are not included as parameters for decision, there is a risk of leading to unintended environmental disservices. The assessment of the impact of vegetation is a demanding challenge that requires sufficient information and analyses to define the measurable indicators are enough to be considered sustainable and to tackle urban mismanagement (Chiarini et al., 2020).

The assessment of the ES 'Reduced Air Pollution' could be an example of this. Despite its high relevance for Lima, it was not considered in the development of the tool for Lima because experiences in dense cities like London (GLA, 2019) indicated vegetation might not always contribute positively towards this ES. The leaves of vegetation facilitate the deposition of pollutants on their surface, while the foliage break pollutant concentration in the air facilitating their dispersion (Beckett et al., 2000). However, deposition is only temporary and limited at the street scale since wind, rain and leaf fall may facilitate resuspension in the air (Nowak et al. 2006). Dispersion, on the other hand, is highly dependent on urban morphology and vegetation type. Figure 24 shows for example, trees implemented in a street canyon above a busy road could prevent polluted air from circulating and mixing with cleaner air above. Hence, in some cases, trees can cause localised increases in pollution concentration. Moreover, trees implemented at roof level (in green roofs), they have little effect on the dispersion of pollution and a relatively minor impact on the removal of pollutants coming mostly from street level. This happens simply as they are far from the pollution source. The distance limits their capacity to perform as a barrier or platform for deposition (GLA, 2019).

Figure 24. Effect of trees on pollution in busy road street canyon (GLA, 2019)



On the assumption that effective performance of GI towards 'Thermal regulation' is achieved under similar spatial and climatic considerations, and that defining the effective delivery of an ES is complex and involves considering a diversity of different parameters (e.g. climate, colour, material, thermal properties, composition, permeability, local appreciation, size, usage, location, etc.), a GAR tool is then a useful planning resource but with limitations. In the case of vegetation and thermal regulation, for instance, the species (e.g. foliage density and its seasonal variation) in combination with the wind direction and surrounding physical conditions may condition principally surface's heat gain and its dissipation due to shading and ventilation capacity. Therefore, the 'Final weightings' attributed to a 'Practice' in a GAR tool should be taken only as a reference. Especially when a 'Final weighting' is high, this may only be an indicator of a high probability of good 'Practice' performance under certain conditions. If such conditions are not adequately described, specialised knowledge about GI and ESs may be needed to avoid disservices.

This is relevant since most of the revised GAR tools did not necessarily address this issue and seem to have not explored further the extent to which encouraging the increase of urban GI may, as well, create conflicts with other for some ESs in certain cases. Contrarily, the achievement of diverse ESs simultaneously was indicated and considered possible, despite the conditionality under which vegetation can help achieve ESs. For instance, eight of the nine cities indicated the ES 'Reduced air pollution' (Figure 11) was a priority in which the GAR tool can contribute. However, there was no evidence explaining how exactly this can happen. Moreover, indications on how vegetation achieves other ESs were not found in the tools themselves, nor in their supporting documentation. Despite some cities indicating they used ecological and social studies, these were not clearly specified in documentation. For example, the City of Helsinki Environment Centre (2016) provided a numerical breakdown of their ‘Final weightings’, but it was still difficult to determine how they were calculated. In cases where studies developed outside the city were used, it was also unclear how well these suited or were relevant to the context.

Such limited available information reflects low transparency and potential subjectivity of the tool and leads to questions about how the ESs and ‘Final weightings’ were established and whether their ‘Practices’ achieve the ESs (goals). This also partially validates the appreciation of Keeley (2011) and Barton (2016), who highlighted the lack of transparency of the tool, due to the absence of sources or justifications used to establish the ‘Final weightings’ leaving open questions about the efficiency of the existing tools and their efficiency to avoid disservices.

For the benefit of a potential implementation of a GAR tool in Lima, it is important to provide clear justifications (including sources of evidence) for all ‘Final weightings’. For instance, considering the alarming levels of polluted air in Lima and that local guidelines considered it is surmountable through vegetation’s ratio increase, it is important to reconsider the level of guidance and to foster further research to support this. This could help clarify the synergies between ESs, especially between ‘Reduced air pollution’ and ‘Thermal regulation’ in Lima and within the constraints of urban water scarcity. For the case of the GAR Lima, detailed explanations of how ‘Final weightings’ were determined is included in section 5.2.3.

6.2. CONTRIBUTION OF THE SELECTED PRACTICES TO LIMA

Much can be written about how the selected ‘Practices’ ultimately contribute to achieving the final selected ESs. Given the scope of this study and its main research objectives, the discussion here will focus on how such ‘Practices’ would finally contribute to achieving the ES ‘Thermal regulation’ and, therefore, the mitigation of UHIs, under the lens of ENVI-met microclimate analysis.

6.2.1. THERMAL REGULATION AND URBAN HEAT ISLAND MITIGATION IN LIMA

The ENVI-met analysis indicated overall that covering outdoor surfaces with vegetation and water would bring the highest cooling effect. Non-vegetated surfaces or partially vegetated (e.g. ‘Bare soil and ‘Combined green/grey surface) varied in their warming effect across the day (Figure 15). Particularly ‘Bare soil’, a surface naturally found in Lima’s desert surface, showed a milder warming effect if compared to ‘Concrete’ or ‘Asphalt’ (on average 0.5°C less than the Base Case streets of ‘Asphalt’), revealing the detrimental impact of sealing surfaces and changing the natural urban surface as part of densification.

Nevertheless, hard surfaces and other non-vegetated surfaces showed potential to be improved (become cooler) if covered by ‘Shading units’ or by hosting ‘Vegetation units’ or by being coated with high-reflective surfaces ‘Reflective surface’ in the GAR for Lima). Surprisingly, adding ‘Trees’ (Figure 17) to a surface fully covered by solely ‘Bare soil’ or ‘Lawn’ helped reach the same level of temperature, suggesting that replacing ‘Bare soil’ with ‘Lawn’ in an area already covered by ‘Trees’ does achieve better ‘Thermal regulation’ – at least in this ENVI-met model. Consequently, it is the shade provided by ‘Tree’ which contributes the most to achieve a cooling effect. This is relevant, principally for an arid context, as it is an indicator that increasing green areas arbitrarily will not necessarily ensure better ‘Thermal regulation’.

6.2.1.1. GREEN ROOFS

There was no specific evaluation of the contribution of green roofs as one unique ‘Practice’. They were instead included as a composition of ‘Surface systems’, ‘Vegetation units’ on ‘Unconnected soil’ with different depths: shallow and deep. Some measurements were done to observe their contribution when placed at roof level (vegetation covers at roof level), which could have helped determine their contribution to Lima’s streets and roofs areas in terms of thermal regulation. The results obtained, however, were inconclusive. They partially contradicted the results obtained for vegetated surfaces (cooling effect) when placed at the street level of the same ENVI-met model as well as some literature about green roofs.

For instance, Figure 16 showed that changing the roof (placed at 15 m) covered by 'Red terracotta tile' of the Base Case for another hard surface roof like 'Concrete' has a negligible impact on the air temperature above the streets of the model (at 2.50 m). Even when changing it to a vegetated surface such as 'Lawn', 'Wetland' and 'Shrub' in both, extensive and intensive systems, the negligible values were maintained. While the distance between the street and roof levels could have been an influencing factor, the results coming from measurements taken above the roof surface of the same cases showed a minimal impact as well. A maximum reduction of only 0.07°C (at midday 2.5 m above the green roof surface, Figure 16) was observed, suggesting there is a minimal impact on air temperature above the roof when covering roofs composed by hard surfaces with vegetated surfaces.

These results may be a consequence of the flat and uniform roof morphology used for the simulation in ENVI-met. As shown in Figure 7, all building blocks had the same height (15m) and roof surfaces lacked physical obstacles, which may have facilitated the wind to efficiently ventilate the roof area, effectively mitigating any warming effect produced by any 'Practice'.

Considering the cooling effect observed in Figure 15 and Figure 18, where 'Lawn', 'Groundcover', 'Tree' and 'Shrub' allocated at street level did produce a cooling effect in the street area and that Speak et al. (2013) observed an air temperature reduction of up to 1.06°C above an intensive green roof surface (0.30 m above the roof surface when compared to a paved roof), the results obtained from implementing any surface cover at roof level were considered inconclusive. While the street-canyon morphology of the ENVI-met model could be equivalent to a more complex rooftop morphology than the one originally used, it is nevertheless insufficient to conclude vegetated surfaces (in the shape of green roofs) placed at roof level produce an outdoor cooling effect in local roofs as well as in streets.

Therefore, further research is then needed to establish the contribution of green roofs in the scope of Lima. Studies should consider analysis under different types of urban morphologies and with measurements at different heights, not only since local policies primarily discuss and foster the implementation of green roofs mostly at roof level, but also because these are also placed commonly at street level, as structural systems that cover underground parking under buildings. Despite the performance of green roofs placed at street level may potentially be equivalent to the one of any other vegetated surface with 'Connected soil' an increased area of green roofs at pedestrian level, using a large proportion of the plot may result in higher amounts of vegetated area on 'Unconnected soil', which may bring some limitations for the preservation and development of natural ecosystems.

In terms of thermal regulation, the results showed that there are no significant differences between a connected soil or a deep or shallow soil (Figure 19). However, the latter, typically 15cm approximately, limits the development of certain vegetation species, but principally of tall ‘Trees’ since these require deeper soils to support root growth (1 m and much more). While this could set intensive green roofs as a better option, it should be as well considered the extent to which intensive green roofs may constrain the preservation of the phreatic napa or local biodiversity, by allowing the growth of solely certain species with certain heights, or by constraining the growth of tree-species that contribute to generate shaded pedestrian areas. Given that ‘Vegetation units’, such as ‘Trees’ improved the thermal performance of non-vegetated surfaces (e.g. reduction of 0.58°C on ‘Bare soil’ and 0.50°C on Asphalt), it should then be considered the relevance of maintaining soils without underground physical obstructions (‘Connected soils’) to facilitate tree-planting and the achievement of other ESs, principally of the ‘Supporting group’.

Ultimately, apart from assessing under a more complex urban morphology in ENVI-met, it may be prudent to use a different scoring approach for the ES ‘Thermal Regulation’. The tool for Lima could look at the impact produced by different surfaces, depending on whether they are applied at the roof or street level.

6.2.1.2. GREEN WALLS

‘Green walls’ were expected to contribute with a cooling effect as any other vegetated surface. However, their ENVI-met analysis indicated they had a warming effect (Figure 13), at almost the same level of hard surfaces, such as ‘Asphalt’ and ‘Concrete’. Such results were introduced in the EPA to determine the ‘Final weightings’. However, they would still demand further analysis given that overall vegetation surfaces in this analysis (e.g. ‘Groundcovers’) demonstrated having a cooling effect (Figure 15) which was consistent with the literature review.

The negative performance of ‘Green wall’ observed in the ENVI-met model may be a consequence of the outdoor warming effect produced by the quantity of ‘Asphalt’ and ‘Concrete’ of other surfaces of the model, which may have been intense enough to mitigate the cooling effect produced by the vegetation composing the ‘Green walls’. The potential cooling effect of its vegetated surface could have been also minimized by the lack of shade provided by the system during the day. The horizontal position of vegetated surfaces covered the ground surface and shade it. Together with vegetation’s evapotranspiration, this could have contributed significantly to neutralise the warming effect produced by the surrounding hard surfaces.

This poor performance led ‘Green wall’ to receive a low score in the EPA, despite being vegetated. Therefore, further simulations of this system are needed under different locations, substrate thickness and foliage densities, to establish conclusions about their thermal impact in the outdoor air temperature of Lima and to adjust its 'Final weighting' in the EPA. It would be relevant to deepen in the conditionality of being a vertical system in almost an equatorial latitude. This could be a reason for its limitations or could discourage its local implementation, which subsequently could negatively affect the delivery of other ESs that these systems may indeed bring.

On the other hand, the results show that the positive impact of vegetation will be always conditioned by diverse inherent factors, like foliage density, but also by the surrounding spatial conditions, such as the surface ('Practice') and the quantity of surrounding hard surfaces, ventilation and climatic factors. These can be obstacles for some vegetated 'Practices' to perform efficiently as UHI mitigation measures and reveals the relevance of proper studies to establish a GAR-Target, as this will be ultimately a key indicator to determine the ratio of vegetation needed to overcome local environmental challenges derived mainly from densification and subsequent hard surface increase.

This should then raise awareness about how polices based solely on the promotion of increasing vegetation quantity arbitrarily may be insufficient to achieve environmental quality, at least from the perspective of outdoor 'Thermal regulation'. Achieving the ES 'Thermal regulation' (UHI mitigation) should not be dependent on the conversion of local surfaces to vegetated ones, especially within a naturally arid environment and water-scarce context. Other alternatives should be explored.

6.2.1.3. XERISCAPE AND WATER SENSITIVE DESIGN

To favour water conservation but keep large areas of vegetation in the urban landscape, local guidelines (Appendix 2) encourage different measures such as irrigation coming from water treatment plants, and also Xeriscape design principles.

This study found that certain principles of Xeriscape could increase outdoor temperature - a trend already identified by Yang and Wang (2017) and Chow and Brazel (2012) in the city of Arizona, United States, where Xeriscape design principles were intensively implemented to overcome similar water challenges to Lima. As seen in Table 2, Xeriscape fosters limited but functional vegetation. For instance, lawn areas should preferably facilitate human activities, which better justifies their water consumption by providing direct connection and interaction between people and nature.

However, Xeriscape also suggests limiting vegetation cover, which may unintendedly encourage leaving significant areas of exposed 'Bare soil, and 'Gravel' - and in some cases 'Sand' and 'Mulch'. Considering that the ENVI-met results showed that a scenario of streets fully covered by 'Bare soil' and 'Sand' could produce in average a mild warming effect across the day (Figure 14 and Figure 15), certain Xeriscape design approaches could potentially lead to achieving a similar outcome as Arizona.

‘Bare soil’ and ‘Sand’ may not increase air temperature to the extent that streets covered by hard surfaces such as ‘Concrete’ or ‘Asphalt’ could do it but large surface areas including these materials may still lead to achieve a detrimental local thermal effect during most part of the day. While ‘Gravel’ and ‘Mulch’ could not be analysed with ENVI-met, based on literature it was concluded for the EPA these ‘Practices’ could have a similar effect. This was assumed since all they fit into the ‘Permeable surfaces’ classification, which according to literature are not as thermally detrimental as hard surfaces (Table 18).

Therefore, it is important that local planning policies pay more attention to design approaches with limited vegetation surfaces and overcome this by improving design guidelines. Requesting just a Xeriscape design approach may set the city in a risk of experiencing higher temperatures and may be insufficient to achieve environmental quality.

On the other hand, it is expected that in such arid conditions not only these ‘Permeable surfaces’ appear as alternative surfaces to vegetated covers. In Lima, it is very common to find urban GI complemented by large areas of ‘Concrete’ or ‘Asphalt’ and other non-vegetated surfaces. Therefore, the maximisation of the benefits of the ‘functionality’ provided by vegetation is urgent to mitigate potential warming effects.

‘Trees’, for instance, could be an asset due to their capability to shade large areas of the surface, that may not be necessarily vegetated. According to Figure 17. ‘Surface Systems’ - comparison of average air temperature difference at street level across 24 hrs resulting from trees, a ‘Tree’ could contribute to reduce the impact on air temperature produced by ‘Asphalt’, ‘Concrete’ and ‘Bare soil’ surfaces in around half degree in the model. Moreover, in Figure 18. Comparison of impact of ‘Trees’ and ‘Shrubs’ on selected ‘Surface Systems’ – air temperature at street level, it can be seen ‘Trees’ have a higher cooling effect than shorter’ height vegetation types, such as’ Shrubs’. Ultimately, its high ‘Final weighting’ achieved in the EPA reveals its capacity to deliver simultaneously different ESs beyond ‘Thermal regulation’.

Therefore, low water-consumption ‘Trees’ with dense shading canopies, instead of other type of surfaces such as ‘Shrub’, ‘Lawn’ and ‘Groundcover’ could be essential resources to maintain a balance between the quantity of vegetation, thermal regulation and water conservation. Moreover, ESs such as ‘Aesthetics’ and ‘Social cohesion and recreation’ among others can be as well favoured. Integrating ‘Trees’ in the urban landscape will contribute to liveability, by creating spaces or ‘cooling islands’ thermally comfortable, especially when the crown is placed above the average human height (approximately 1.80m). These open possibilities to create public urban shelters if strategically placed, especially against heat waves. Furthermore, they can be a key part of publicly accessible and comfortable green spaces, the importance of which has been highlighted through the COVID-19 pandemic.

It should nevertheless be highlighted that the inclusion of trees in densely built urban environments is challenging since it demands spatial considerations that facilitate a healthy growth and reduce conflicts with surrounding urban infrastructure - from here the relevance of including the 'Practice' 'Preserved trees' in the section 'Functional surface'. On the other hand, as discussed for the case of London (section 6.1.1; Figure 24), care about tree-arrangements should be taken as this can unintentionally create conflicts with 'Reduced air pollution'. Therefore, further scientific research in terms of the suitable local spatial arrangement of 'Trees' in the urban environment of Lima is required to determine the extent to which they contribute to 'Thermal regulation' while supporting the improvement of air quality - as well how a GAR tool could provide guidance in this aspect and avoid leading to disservices.

Studies should as well include filling-in the research gaps indicated before in terms of the thermal performance of 'Gravel' and 'Mulch', to improve the accuracy of their 'Final weightings' in the EPA. The capacity of 'Mulch 'to help maintain soil moisture, for instance, was not considered in the EPA. It, therefore, remains unclear the extent to which this could have some impact in evapotranspiration and in the air temperature above its surface. Deepening in the study of 'Permeable surfaces' in the Lima context, could as well be avenue to explore the extent to which a 'sponge city' approach could contribute to other environmental challenges in the arid context, such as erosion, groundwater recharge, potential desertification and the benefits against sea level rise. 'Gravel', for instance, may contribute effectively to 'Flood risk reduction'. Considering that this ES is commonly addressed through grey infrastructure such as drainage systems or pipe networking - which in the urban area of Lima are almost non-existent - the promotion of 'Permeable surfaces' could be a valuable contribution to Lima's resilience against potential river flooding events or unexpected rainfall events due to El Niño. Research in all these aspects can help better reflect the value (score) of these 'Practices' and will help in the calibration of the GAR tool for Lima.

6.2.1.4. WHITE COATINGS ON HARD SURFACES

At a local level, the implementation of 'high-albedo roofs' to reduce urban temperature can sometimes be interpreted in different ways. While some local guidelines specifically refer to 'cool roofs' or 'high SRI' (e.g. SRI 70% (MM, 2019) or SRI 82% (USGBC, 2009), others refer to the approach used in Los Angeles, United States, where white coatings were applied to streets surfaces of concrete and asphalt (See PROACC, 2017, p.95). In this study, high albedo roofs were modelled using an SRI-value of 100%

and tested variations of high albedo applied to only ‘Asphalt’ and ‘Concrete’ surfaces, which are the most common roof and street surfaces in Lima.

Similar to the measurement of the impact of green roofs at roof level, only the impact of high-reflective surfaces placed at and measured above the street level was considered valid. Figure 20 showed ‘Concrete’ and ‘Asphalt’ with white coatings, namely high-albedo surfaces, produced a considerable temperature reduction above their surfaces across the day (between 7:00 and 20:00 hours). Regardless of the base material, the cooling effect in both cases was almost the same across the day, and very similar to the cooling effect seen in the streets fully covered by ‘Lawn’, principally between 8:00 and 16:00 hours.

While this is of significant contribution for local thermal regulation, the extent to which this ‘Practice’ (white coatings) represents a sustainable alternative demands certain reflection, especially from the perspective of maintenance and the delivery of ‘Cultural’ ESs. Lima deals high levels of air pollution (IQ Air, 2018), which can make high SRI surfaces dirty, negatively affect the reflective performance of the surface and demanding constant maintenance. On the other hand, while high-albedo or white surfaces are commonly implemented at rooftops, they can be as well implemented at street level. Despite no major disturbances related to glare in public areas have been reported by some cities applying this ‘Practice’ (Akbari et al., 2001), it should be nevertheless assessed the extent to which it facilitates or constraints the local development of ESs related to leisure and aesthetics, especially when used as a pedestrian or transit surface.

It is also important to consider that white roofs, as well as green roofs and green walls, may have a more indirect than direct contribution to the mitigation of UHIs and outdoor thermal regulation. It has widely proved these systems perform as insulation layers for building surfaces. They cool indoor areas, reducing the need for air conditioning during warm days and subsequent production of related heat and emissions (Osmond and Sharifi, 2017). While the use of air conditioning and heating systems in buildings in Lima is still limited, it is a practice in growth (INEI, 2018 cited in Espinoza Castillo, 2020). From this perspective, these systems are then beneficial to stop this increasing trend. However, the indoor cooling effect can also occur in winter, increasing the demand on energy to heat the interior.

Therefore, it is important to explore in greater depth how these surfaces can be better integrated into the urban form (roof, walls, paths, etc.) and landscape and to evaluate its performance with more simulations in all seasons of the year under local climate. This could contribute to achieving a sustainable balance between its maintenance, the development of daily activities, and its integration into the local urban landscape without causing negative impacts.

6.3. THE GAR LIMA

The resulting tool, the 'GAR Lima' (Table 15), followed the 'Practice' structure and classification already seen in previous GAR tools. Therefore, its composition is very similar to some existing GAR tools at first sight.

The GAR Lima is composed by a set of varied 'Practices' divided in 4 sections that were not limited to a classification based on just physical attributes or types of surfaces as in the original tool: BAF -Berlin (e.g. permeability in section 'Surface system'). It also considered rewarding the use of vegetation in a scattered way ('Vegetation unit') – for instance placed on 'Bare soil' or 'Gravel' as commonly seen in Xeriscape (Figure 25); implementing shaded areas ('Shading units') and considered social, cultural, maintenance, use and comfort aspects. The 'Functional surfaces' section was, precisely, created to account for these.

Figure 25. Typical scattered vegetation and combined ground surfaces of xeriscape gardens

Each 'Practice' in each section scored a 'Final weighting' in the EPA, which is essentially an indicator of the feasibility of each 'Practice' to deliver varied ESs simultaneously. The 'Final weightings' in the section 'Functional surfaces' helped establish indicators for key common local preservation, accessibility and maintenance approaches, such as the donation of private areas. The voluntary permission to use private areas as public or shared spaces may facilitate recreation and social interaction whilst decreasing the number of fenced green spaces in Lima. It should be noted, however, that the practices under 'Functional surfaces' resulted lower than others because they were not assessed against all ESs. Nonetheless, they were only included to complement the 'Final weightings' of other 'Practices' in other sections - similar to the bonus-system of Malmö discussed by Kruuse (2011). Therefore, their 'Final weightings' does not necessarily define a scale of relevance or are comparable against other 'Final weightings'.

In order to account for the benefits derived from each section, the GAR Lima uses the ‘layering’ system. Consistently with Kruuse (2011), this resulted in a practical approach. Common local ‘Practices’ with different type of attributes and in some cases not necessarily measurable based on area could be simultaneously accounted. For instance, all the attributes of a non-vegetated surface but with scattered and preserved trees with high foliage and irrigated by a treatment plant could be determined. While for practicalities the shade produced by the foliage was accounted as the area of the projection of the tree crown on the surface at the time of maturity, it does not mean this could be the most suitable metric. Further ways to improve this measurement should be explored, for example by using the Leaf Area Density or similar metrics.

6.3.1. THE RELEVANCE OF GREEN INFRASTRUCTURE FOR THE SUSTAINABLE DEVELOPMENT OF LIMA

While the ‘Final weightings’ of any GAR tool should be interpreted carefully, they nevertheless provide an indication of the relative importance of a ‘Practice’ for a city. The ‘Final weightings’ demonstrated vegetation having a significant positive impact in Lima’s sustainable development. Almost all vegetated ‘Practices’ overall achieved considerably high ‘Final weightings’ (Table 15) (e.g. ‘Wetland, as water treatment plant’ - 1.00, ‘Shrub’- 0.67, ‘Groundcovers’ – 0.67 and ‘Tree’ – 0.78), indicating the presence of GI in Lima is highly relevant despite aridity and water scarcity. Such values demonstrate that GI can simultaneously deliver a varied of ESs that will certainly contribute to developing resilience against climate change and other Lima’s environmental and social relevant challenges such as liveability, food security, social cohesion, protection of habitats, water conservation and quality, among others. Therefore, the efforts for increasing their quantity in the city are justified.

However, some vegetated ‘Practices’ contribute more than others. ‘Groundcovers’ and ‘Lawn’ achieved higher ‘Final weightings’ than ‘Green wall’. Apart from it scoring low only in the ES ‘Thermal regulation’, ‘Green wall’ achieved a ‘Final weighting’ of 0.33 almost as low as ‘Asphalt’ and ‘Concrete’. It is consequently relevant that local planning policies be aware of this fact before arbitrarily fostering GI increase based on one particular type of vegetated system or cover. It is important to establish clear goals on what it is aimed through vegetation given water scarcity and limited space in the urban scenario. Therefore, guidance with a strategic approach is key to help maximize the benefits of the few local vegetated areas.

A strategic approach towards vegetated surfaces and their combination with others to overcome water scarcity is also consistent with research work about landscape design in arid areas. Ivanir et al. (2015), for instance, identified in the design work or ‘Aridscapes’ of Shlomo Aronson (2008) that adequate landscape design in the desert encompassed facets such as comfort, materiality, water, culture and maintenance. They found this, by assessing Aronson's landscape work through a 'Spectrum of Desertness' - a so called green-to-brown/grey landscape scale (Figure 26). This scale helped the authors visualize that Aronson's work fit in the middle of the scale, as a way of proposing a balance between the 'highly-green' expectation of certain landscaping approaches and the natural condition of deserts ('genius loci'). According to Ivanir et al. (2015), this helped create a green oasis that contributed also to achieve thermal comfort in such environments.

Figure 26. 'Aridscape' projects of Aronson allocated in the 'Spectrum of Desertness' of Ivanir et al. (2015)

The consideration of the facets of Ivanir et al (2015) seems to be highly aligned to the 'Functional surfaces' concept of the GAR Lima and the resulting scale of 'Final weightings' to their spectrum. These similarities indicate there is a need to recognize the limitations of arid environments and moderate high vegetated expectations, by identifying the positive and negative attributes of the elements and surfaces implemented in the landscape and using them strategically to deliver urban and environmental benefits. In that sense, the GAR Lima could be a tool that supports achieving such goals.

6.3.2. A GREEN (BUT BROWN & GREY) AREA RATIO TOOL

The clear high-to-low delineation between vegetated and non-vegetated 'Practices' identified in the 'Final weightings' (factors) of existing GAR tools does not occur in the GAR Lima. Hard surfaces 'Asphalt' and 'Concrete' did not score zero (but 0.33) (Table 15) as seen in most existing GAR tools (Table 7). Moreover, some vegetated 'Practices' resulted with relatively low 'Final weightings' (e.g. 'Lawn' 0.56 and 'Green wall' 0.33), while some non-vegetated 'Practices' resulted with relative higher 'Final weightings' (e.g. 'Bare soil' 0.70 and 'Gravel' 0.63). Due to this condition, the GAR Lima can be considered a kind of Green - but Brown/Grey - Area Ratio Tool.

This, in addition to the discussions of Ivanir et al. (2015) and Aronson (2008), indicates GI in arid contexts might need to be supported by other type of infrastructure to result beneficial in the urban scope - conditions possibly unnecessary within non-arid conditions.

The city should be then strategic when GI is combined with other type of surfaces. It should look for ways to benefit from the combination of vegetated surfaces (GI) with other surfaces. For instance, consistently with Chow and Brazel (2012), through shading methods in water-sensitive approaches such as Xeriscape; nature-based solutions such as artificial 'Wetlands' to treat water; and the positive symbiosis between green roofs covered by 'Solar PVs' (Leonard and Leonard, 2005 cited in Tolderlund, 2010). Planning schemes should be clear, for instance, that large areas of 'Concrete' or 'Gravel' could be suitable and justified as long as they are properly shaded, preferably by a 'Tree' covering pedestrian infrastructure. Similarly, efforts for maintaining 'Lawn' areas should be primarily targeted for public use and configure sufficient useful area for recreation, instead of being narrow and merely decorative for car verges. Nonetheless, given the complexities that these approaches, it could be necessary to consider other alternatives (less dependent on vegetation) to overcome local urban environmental challenges. Mechanisms to deconcentrate the city such as improving the services, infrastructure and liveability of neighbourhoods in other cities could be of great contribution.

Ultimately, it is also important to reflect on vegetation increase as a compensation for hard surface increase under arid and water scarcity conditions. It is highly relevant to find mechanisms to determine whether there is an 'ideal' local proportion of vegetation within such a densely built environment like Lima's to overcome environmental challenges. Policies and planning schemes are commonly based in vague indicators such as the '9m2 of green area of area person' attributed to the World Health Organisation - which apart from being not properly documented with a non-identified origin and source - does not lead to a specific goal or serve as a clear metric to measure local improvement in terms of vegetation quantity and urban quality. From here, there is a need to finding resources to quantify the benefits of GI and monitor its impact at a local level over time - since as seen this study, increasing GI may not necessarily lead to an increase in environmental quality within the Lima context.

6.3.3. THE TOOL AS A PLANNING INSTRUMENT

The application of the GAR Lima to three local projects (Table 22) and further scenarios of one of them (Figure 22 and Figure 23) illustrated the extent to which the tool can adequately guide in the maximisation of the benefits of ESs delivered by GI within outdoor areas, especially while keeping a balance between 'Water saving' and 'Thermal regulation'. It also revealed the limitations of the tool as a metric of sustainability.

6.3.3.1. QUANTITY VS. QUALITY

The results from applying the GAR Lima to the outdoor areas of three local projects suggested the quantity of vegetated area – namely, the percentage of vegetated area (Table 22) - does not necessarily correlate with the ecological functionality.

While 'Olavide' implemented approximately four times more the percentage of green area within its plot, it reached the same ecological functionality as 'Palas' (same GAR Lima-Score 0.47). Further, its approach to GI and other ground surfaces, as well of the one of 'Palas', resulted both in a lower GAR Lima-Score compared to the project 'Huaylas' (0.50), which was built under a traditional approach (e.g. without green roofs or solar panels). This means that the efforts for covering urban outdoor surfaces with vast vegetation may not necessarily result in a higher environmental contribution and delivery of ESs relevant for Lima.

Therefore, local 'sustainable' ordinances and regulations that support the increase of densification, in return for higher quantities of vegetation than normal, on the projects' outdoor roof, walls and ground surfaces, are financially rewarding measures that may not necessarily bring a significant net ecological benefit, at least from the perspective of the nine ESs included in the GAR Lima. The revised local guidelines may not be properly (or necessarily) addressing the sustainability concepts included in the ESs of the GAR Lima (e.g. strengthen social cohesion, habitats, urban heat island mitigation, aesthetics, etc.) or may be insufficient when helping developers maximise the benefits of vegetation within a plot. Moreover, having international sustainable building certifications as part of local guidelines could be also leading the concept of local sustainability towards the pursuit of benefits mostly focused in the indoor scope of the building (for the building and users) rather than to its outdoor scope (for the public space), unless they quantitively demonstrate the benefits are also reaching a city or neighbourhood scale – for instance, by demonstrating the inclusion of private greenery on building surfaces is decreasing substantially the intensity of UHIs in neighbourhood streets of Lima. Otherwise, it is then relevant to explore how the international indicators and sustainability measures implemented within the plot impact also beyond its own limits.

Further studies should also consider exploring the consequences of the implementation of water-treatment plants to increase vegetation quantity. The GAR Lima can give very high GAR Scores to vegetated 'Practices' that come with water-sensitive design approaches, such as 'Lawn' or 'Groundcovers' irrigated with treated greywater. However, the tool does not consider the implications of the latter in energy. Besides looking for alternatives to overcome this weakness, there should be a reflection on the extent to which promoting the installation of small domestic greywater treatment plants individually and privately is beneficial. Consistently with Shaka (2015), this 'Practice' will indeed benefit arid environments, but it may end satisfying solely individual and private needs. Therefore, the exploration for alternatives to integrate collective domestic grey water-treatment plants per neighbourhood (rather than per plot) deserves more attention, especially if they come in the form of NBSs. Artificial wetlands, for instance, could as well contribute with a cooling effect due to its vegetated-based composition and the demand of space needed for their implementation could be overcome if they are placed in areas bigger than just a typical Lima's plot-yard (e.g. parks). Eisenberg et al., (2014) and Vargas Moya, (2020) have already explored the potential benefits of this approach in Lima. Their studies could make a valuable contribution to calibrate the GAR Lima to ensure all surfaces and elements quantity, as well as their functions, reflect their actual level of environmental quality.

6.3.3.2. FINDING A BALANCE

The resulting GAR-Scores applied to 'Olavide' show the ability of the tool to support planners on the valuation of ecologically functional areas, when implementing the most suggested and common 'Practices'. As well, they helped observe the resulting level of calibration of the tool, especially when pursuing a balance between 'Water saving' and 'Thermal regulation'.

Due to the initial interest on these ESs and the limited scope of analysis of this study, the diverse scenarios of 'Olavide' (Figure 22 and Figure 23) integrated principally surface design combinations that facilitated the analysis of only these two ESs. This was considered a starting point to obtain a first insight of the level of calibration of the resulting tool. Under this consideration, it was expected that the highest GAR Lima-Scores would be achieved by water-sensitive scenarios mainly composed by surfaces supporting UHI mitigation (e.g. drought tolerant trees with vast shaded areas); and low GAR Lima-Scores would be achieved by scenarios with significant areas of hard surfaces (e.g. roofs with exposed concrete). Indeed, at the extremes of the scoring spectrum (Figure 23), the lowest GAR Lima-Scores (A1=0.44, A2=0.37 and A3=0.33) were obtained by scenarios where only hard and sealed surfaces were implemented and the highest GAR Lima-Scores (Figure 22) were obtained by scenarios with a high dense foliage but water-sensitive (e.g. xerophyte species) (X1=0.84, G1=0.73, X2=0.69).

Within this spectrum, the GAR Lima-Score of the Base Case (BC=0.47) resulted with a position at almost the end of the spectrum (Figure 23), possibly due to its non-water-sensitive fully vegetated green roof approach without connected soil in all surfaces. If all the building roof surfaces would have instead been covered with white or high-SRI coating (A1), this would have slightly decreased the GAR Lima - Score to 0.44. Nonetheless, this would have been a slightly better scenario than a traditional roofing approach (A3=0.33) – seen, for instance, very often in informally self-constructed buildings.

Partially covering with green roofs the building's outdoor areas would have overall always resulted in a higher ecological functionality than sealed and hard surfaces, even when compared to systems mimicking vegetation (A2 = 0.37). Nevertheless, some green roofs approaches were significantly better (e.g. X1, G1 and X2), namely more ecologically functional than the BC, and some others resulted only slightly better (e.g. G9 and G6), meaning that it will depend much on the design of the green roof to effectively obtain the most benefits derived from its composition.

These results also suggest, that in the case of Lima, a green roof may not necessarily be an alternative of similar value or comparable functionality to a roof painted white or coated with high-SRI, even though such green roof is designed under Xeriscape design principles. Nevertheless, both green and white roofs are commonly promoted locally as 'eco-friendly' alternatives for buildings, which could be unintendedly creating a gap in the understanding of the main ecological purpose behind their implementation. For the benefit of the local sustainability and the strengthening of knowledge in this field, it is then necessary to offer more transparency about the targets the guidelines finally pursue: what 'sustainability' means in the local context, and whether this would possibly be more focused to an economic, social or even thermal dimension.

On the other hand, on the basis that G7 (0.53) and G8 (0.50) are likely to appear in Lima as a result of water scarcity or high maintenance costs of vegetation, which subsequently could put in risk the achievement of the ES 'Thermal regulation' due to lacking vegetation and vast areas of exposed 'Bare soil' or 'Gravel', it is therefore important that the promotion of fully vegetated scenarios is reconsidered, since partially-vegetated design approaches (e.g. X5=0.57) could bring to some extent the same ecological functionality, potentially at a more feasible cost and with less maintenance. This could ameliorate the existing trend to comply with regulations to 'just tick the box' and refurbish or neglect the initial proposal after having complied with the building authority revision. This may also help reduce the need to constantly monitor the permanency of the initial proposal.

6.3.3.3. LIMITATIONS AS A PLANNING TOOL

At the middle of the spectrum, some GAR Scores revealed inconsistences under the lens of 'Thermal regulation', that may as well be linked to the level of calibration of the resulting tool. If the scenario X5 (0.57) is compared to more ecologically functional scenarios such as X3 (0.69) and X4 (0.65), it can be observed X5 has the ground surface probably better shaded due to apparent less scattered foliage. Nevertheless, it scored significantly lower. Also, X3 resulted with the same GAR Score as X2 (0.69), despite the foliage of the latter having much potential to shade the entire ground surface. Similarly, X4 (0.65), with a similar limited shading approach, resulted only slightly less ecologically functional than X2.

Such 'inconsistences' for 'Thermal regulation' could find a source in the way the GAR tool works as an average-based calculation system. The tool inherently allows that the poor performance of a 'Practice' achieved in one ES to be compensated by its good performance in achieving another. With a large number of ESs, there is a risk that a poor performance be masked by a high 'Final weighting' and the relevance of certain ESs be diluted. For instance, a 'Practice' could achieve good performance against 8 ESs but be severely detrimental in one that is highly relevant for the city. This can result in an overall good 'Final weighting', that results ultimately inappropriate in a critical aspect for the local context and contradictory to the concerns of the city.

Whereas the effectiveness on the implementation of GI sensitive to both ESs 'Thermal regulation' and 'Water saving' simultaneously was the aim of the GAR Lima, additional ESs (at least one ES per Service Group) were included. The tool addresses finally 9 different ESs, which is potentially ambitious and risky if compared to other tools. According to this study, the BAF was conceived to pursue only 4 ESs highly related to ecology (Figure 11) or up to 6 ESs according to the analysis of Keeley (2011) (Table 9).

Nevertheless, including 9 ESs was appropriate. Developing a GAR tool to evaluate the sustainability of the GI in Lima, without considering the cultural and social synergies that it also develops, could have omitted key aspects to warrant a sustainable development in Lima. According to Chiarini et al. (2020), subjective indicators and several dimensions should be considered in integrated analysis of environmental quality and sustainability within urban environments. Moreover, subsequent versions of the BAF, such as the tools of Washington, Stockholm and Seattle, seemed to be aligned with this stance, suggesting the GAR can be considered also as a resource to support in the urban social dimension.

In order to accommodate the large number of ESs, the 'Prioritisation factor' was therefore introduced to ensure 'Practices' which delivered ESs of the highest importance in the local context could score high 'Final weightings'. This mechanism has also been used in tools for sustainability measurement. Edwards (2014), for instance, indicates the addition of multipliers in tools such as LEED and BREEAM helps give priority to certain values and allows adjustments to better reflect local interests and concerns. In the case of the GAR Lima, in addition to the ESs 'Thermal regulation' and 'Water saving', a high 'Prioritisation factor' (value = 3) was assigned to the ES 'Social cohesion and Recreation', given the socio-cultural conflicts, widely reflected in fenced GI. This was supposed to ensure a local approach but also sustainability reaches different dimensions.

However, 'Prioritisation factors' alone were insufficient to avoid 'Practices' achieving high 'Final weightings' despite having a considerably detrimental effect under one of the prioritised ESs. For instance, despite ‘Groundcovers’ and ‘Trees’ having a ‘detrimental’ effect against water conservation, they obtained high ‘Final weightings’ because they scored highly against ‘Thermal regulation’ and other ESs. On the other hand, despite ‘Gravel’ and ‘Sand’ performing poorly against ‘Thermal Regulation’, they received relatively high ‘Final weightings’ due to their high score in the ESs ‘Aesthetics/ Visual interest’ and ‘Water saving’ (no irrigation).

These shows the resulting GAR Lima as a planning tool has limitations, but as a novel approach it has also possibilities for improvement. For instance, to avoid such detrimental scenarios, the tool could be supplemented by additional controls to ensure minimum standards are achieved under certain ESs. To ensure achievement in all prioritised ESs, a GAR-Sub-Target to the GAR-Target could potentially be incorporated, so that a balance between both ESs (‘Thermal regulation’ and ‘Water saving’) can be better monitored. Alternatively, a separate calculation of the contribution of ‘Practices’ solely to each ES could be required and individual targets for these metrics could be set as part of implementation, in addition to a broader GAR-Target.

7. LIMITATIONS

This study presented a series of key limitations that demand further revision. These, and potential ways to overcome them, are presented below:

7.1.1. CREATION OF THE TOOL

- Only less than half of the ‘Practices’ revised in official and academic public sources, including the GAR calculators referred explicitly to the ESs the cities pursued. Therefore, these conclusions are dependent of authors interpretation and could vary if other sources are consulted - for instance, direct consultation with authorities responsible of the creation of one of the nine GAR tool.
- There was limited public information about how existing GAR tools determined the contribution of ‘Practices’ and which mechanisms were used in each case to determine the ‘Final weightings’ of each tool. In the absence of such information, the availability of the work of Keeley (2011) was selected to develop the EPA. However, this does not necessarily mean this is the most suitable ‘Practice-ES’ assessment mechanism to determine ‘Final weightings’. Further sources need to be consulted to compare assessment methods and determine if it was convenient.
- Due to the scope of this thesis, the method of using scientific studies was necessary to determine ‘Final weightings’ in the EPA (except in the ES ‘Thermal regulation’). However, there was limited public scientific studies developed for the local context as to ensure a low level of subjectivity when determining the scores in the EPA. Therefore, a quantitative analysis in the local context, including

measurements in-situ and surveys – instead of scientific literature - is highly recommended to determine more accurate 'Final weightings' in the GAR Lima.

- Three of the twelve initially considered ESs could not be assessed in the EPA: 'Reduced Air Pollution', 'Biodiversity' and 'Noise reduction'. There was lack of clarity on the definition of certain parameters (particle type, noise type, type of species and scale of diversity, etc) in both local guidelines and existing GAR-tool cases that could have served as a guide to proceed with the study. Even when assumptions were made, it was highly complex to determine which parameters could be simplified or which variables could be avoided without leading to disservices, especially without further local research due to the scope of this study or expertise in the topic. This could avenue for further research and be as well overcome with quantitative and qualitative analysis in each ES within the local context.

7.1.2. MICROCLIMATE ANALYSIS

Despite the uncertainties associated with the ENVI-met modelling approach, the results nevertheless provide a reasonable guide as to the relative impact of different 'Practices' (surfaces) on 'Thermal regulation'. Apart from some limitations already mentioned in section 6.2, some other relevant limitations are listed below:

- Material surfaces and vegetation (including colours, types, and vegetation size, foliage and specie) of building and street surfaces were selected in most cases from the software's database. However, in all cases these were not necessarily representative of those found in the local context. Moreover, some materials were not available in the database nor could suitable parameters or alternatives to mimic them could be identified (e.g. for gravel, mulch and solar PV). Considering the progressive improvement of the software ENVI-met and supporting tools such as Albero, it could be of valuable contribution to explore with more depth the attributes of local vegetation and materials, for instance, by parametrising and modelling a local data base with the software, so that local material conditions and properties could be used in a potential further development of this study.
- Apart from being using a simple morphology, the ENVI-met model was simulated only under a single set of conditions on only one summer day. Conditions such as cloud cover, particularly in winter (which results in less sunshine and diffuse light) was not reflected in the model. Therefore, it is highly recommended to develop simulations under different climatic conditions, meaning other seasons, days of the year and consider the performance of all 'Practices' during the night. This can help as well reflect more accurate 'Final weightings'. Overall, it would be useful to conduct sensitivity analyses on the results and validate the scenarios with in-situ measurements using, for instance, temperature sensors.

8. CONCLUSIONS

The GAR is helpful planning tool that can guide the implementation of ecologically functional urban GI. It can contribute to sustainable development by supporting cities to achieve diverse ESs, including water conservation and thermal regulation. Nevertheless, the limitations of the tool should be acknowledged to avoid disservices.

While the tool has been widely used internationally, none of the revised nine existing GAR tools was developed for an arid context. Considering the significant differences in rainfall level, the cities' interests in ESs and their local interpretation of sustainable green areas, principally related to water conservation, it can be concluded none of the cases represent a suitable option for application in the arid context of Lima, unless it is adapted to the city's context. The direct application of any of those GAR tools in Lima could lead to a poor recognition of certain benefits (ESs) that may be key to support Lima's sustainable development or could unintentionally encourage the arbitrary implementation of vegetation solely to increase GI's quantity or achieve a high GAF-Score.

The resulting tool, the GAR Lima, represents a more suitable option. It gathers the most common and suggested GI practices for the arid and Lima context and focuses specifically on local water conservation and thermal regulation concerns given its relevance to the local context. Despite the uncertainties of the ENVI-met model approach – the results indicate that an intensive implementation of hard surfaces (e.g. 'Asphalt' and 'Concrete') will result in warmer outdoor temperatures, setting Xeriscape as a more sustainable corrective measure in comparison to large vegetated areas of high water-consumption. However, an exacerbated implementation of Xeriscape based on limited vegetation cover or scattered vegetation, including large areas of exposed 'Bare soil' or 'Gravel' may also increase outdoor temperature in Lima, unless such surfaces are shaded. 'Tree' is, consequently, a good alternative to mitigate this potential disservice, in comparison to other shading infrastructure and as long it is low water-demand and applied strategically. However, this scenario requires further research, especially when being part of green roofs.

The GAR Lima addresses also further local challenges common of the urban scope, including those resulting from social conflicts around GI. Despite the quantity of ESs, and as it follows the scheme calculation of previous cases, the GAR Lima is flexible and practical. However, it does not necessarily reward highly and solely vegetated practices, unless they come with a strategic approach and consideration for UHI mitigation and water conservation, such as NBSs (e.g. 'Wetlands' for greywater treatment or 'Trees' shading the ground surface). The tool suggests that despite aridity and water scarcity, the presence and increase of GI in Lima is highly relevant for Lima's sustainable development and resilience. However, this is not an indicator that an intensive densification can be effectively compensated by an increased ratio of vegetation. The application of the GAR Lima to three local projects demonstrated that a large quantity of vegetation within a project does not necessarily correlate with higher ecological functionality, at least under the lenses of the ESs included in the GAR Lima. Notwithstanding, the tool demands further in-depth testing and validation, as its application to the retrofitting scenarios of 'Olavide' did not show consistency with a water conservation and thermal regulation in all cases. Some high GAR-Scores were obtained by scenarios supporting principally only one of the two ESs. Such limitations may mislead some implementation decisions, being a risk, especially if the GAR Lima is used without a proper understanding of the limitations of the tool mechanism and GI's within water-scarcity conditions, and the addition of relevant controls.

It is likely Lima's urban GI might need to be present in combination with other ground surfaces or supported by additional infrastructure to avoid disservices and ensure sustainable results within water-scarcity conditions. This may make its implementation more complex in comparison to non-arid cities. Therefore, planning policies and regulations should not consider the increase of vegetation the principal mechanism to overcome local environmental challenges in Lima. Higher attention to other low-carbon practices should be given to achieve relevant ESs.

Ultimately, the GAR Lima should be considered an evidence-based preliminary framework for better informing how to maximise the benefits provided by urban GI within urban developments executed under the constraints of water scarcity. It is a novel approach that presents a useful starting point for a better understanding of the synergies developed between water and UHIs within an arid and dense urban context.

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11.APPENDICES

Appendix 1 – Analysis of practices and ecosystem services included in existing GARs

Appendix 2 – Analysis of practices and ecosystem services included in local building regulations

Appendix 3 – Categorisation of local practices

Appendix 4 – Summary of practices

Appendix 5 – Environmental performance assessment criteria

Appendix 6 – ENVI-met scenarios

Appendix 7 – ENVI-met materials

Appendix 8 – ENVI-met scenario matrix

Appendix 9 – Application of the tool

Appendix 10 – Application of the tool – Olavide project

APPENDIX 1 - ANALYSIS OF PRACTICES AND ECOSYTEM SERVICES INCLUDED IN EXISTING GARS

Practice N°	City	Description	Factor	Practice Group	Practice Type	Practice	Indicated Service	Vegetated	Water component	Unit	Conversion to m2
1	Helsinki	Preserved large (fully grown > 10 m) tree in good condition, at least 3 m (25 m² each)	1.00	Vegetation Unit	Tree	Tree - Preserved	Undisturbed nature	Y	N	pcs	25
2	Helsinki	Preserved small (fully grown ≤ 10 m) tree in good condition, at least 3 m (15 m² each)	0.86	Vegetation Unit	Tree	Tree - Preserved	Undisturbed nature	Y	N	pcs	15
3	Helsinki	Preserved tree in good condition (1.5–3 m) or a large shrub (3m² each)	0.69	Vegetation Unit	Tree	Tree - Preserved	Undisturbed nature	Y	N	pcs	3
4	Helsinki	Preserved natural meadow or natural ground vegetation	0.63	Vegetation Unit	Tree	Tree - Preserved	Undisturbed nature	Y	N	m2	
5	Helsinki	Preserved natural bare rock area (at least partially bare rock surface, not many trees)	0.54	Surface System	Rock	(Finnish) Native rock	Undisturbed nature	N	N	m2	
6	Helsinki	Large tree species, fully grown > 10 m (25 m² each)	0.80	Vegetation Unit	Tree	Canopy Large	Not Explicit	Y	N	pcs	25
7	Helsinki	Small tree species, fully grown ≤ 10 m (15 m² each)	0.66	Vegetation Unit	Tree	Canopy Small	Not Explicit	Y	N	pcs	15
8	Helsinki	Large shrubs (3 m² each)	0.49	Vegetation Unit	Shrub	Shrub	Not Explicit	Y	N	pcs	3
9	Helsinki	Other shrubs	0.40	Vegetation Unit	Shrub	Shrub	Not Explicit	Y	N	m2	
10	Helsinki	Perennials	0.46	Vegetation Unit	Shrub	Shrub	Not Explicit	Y	N	m2	
11	Helsinki	Meadow or dry meadow	0.51	Functional Surface / Functional Element	Soil	Open soil	Not Explicit	Y	N	m2	
12	Helsinki	Cultivation plots	0.57	Functional Surface / Functional Element	Area / Space	Cultivation	Urban Agriculture/Food	Y	N	m2	
13	Helsinki	Lawn	0.31	Surface System	Permeable surface	Lawn	Not Explicit	Y	N	m2	
14	Helsinki	Perennial vines (2 m² each)	0.37	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	pcs	2
15	Helsinki	Green wall, vertical area	0.26	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
16	Helsinki	Semipermeable pavements (e.g. grass stones, stone ash)	0.29	Surface System	Permeable surface	(Block) With joints	Not Explicit	N	N	m2	
17	Helsinki	Permeable pavements (e.g. gravel and sand surfaces)	0.40	Surface System	Permeable surface	Gravel	Not Explicit	N	N	m2	
18	Helsinki	Impermeable surface	0.00	Surface System	Impermeable surface	Impermeable surface	Not Explicit	N	N	m2	
19	Helsinki	Rain garden (biofiltration area) with a broad range of layered vegetation	0.80	Stormwater Management System	Detention, Retention and Infiltration system	Raingarden	Flood risk reduction	Y	N	m2	
20	Helsinki	Intensive green roof / roof garden, depth of substrate 20 – 100 cm	0.57	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
21	Helsinki	Semi-intensive green roof, depth of substrate 15 – 30 cm	0.43	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
22	Helsinki	Extensive green roof, depth of substrate 6-8 cm	0.40	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
23	Helsinki	Infiltration basin or swale covered with vegetation or aggregates (no permanent pool of water, permeable soil) Vegetated depressions, designed **to store** run-off on the surface and infiltrate it gradually into the ground. They are dry except in periods of heavy rainfall.	0.66	Stormwater Management System	Detention, Retention and Infiltration system	Basin/Reservoir/Pond	Flood risk reduction	Y	N	m2	
24	Helsinki	Infiltration pit (underground) An infiltration pit is a sub-surface run-off detention and infiltration system. It is usually located close to the downspout from the roof collecting stormwater in an underground storage space. The storage space is composed of large rocks, geocellular system or other material, that infiltrate stormwater and allow detention.	0.43	Stormwater Management System	Detention, Retention and Infiltration system	Detention, Retention and Infiltration system	Flood risk reduction	N	N	m2	
25	Helsinki	Pond, wetland or water meadow with natural vegetation (permanent water surface at least part of the year; at other times the ground remains moist)	0.80	Stormwater Management System	Detention, Retention and Infiltration system	Basin/Reservoir/Pond	Flood risk reduction	Y	Y	m2	
26	Helsinki	Retention or detention) basin or swale covered with vegetation or aggregates (permeable soil)	0.57	Stormwater Management System	Detention, Retention and Infiltration system	Basin/Reservoir/Pond	Flood risk reduction	Y	N	m2	
27	Helsinki	Retention or detention) pit, tank or cistern (underground, notice units: volume!)	0.40	Stormwater Management System	Water harvesting system	Water harvesting system	Water saving	N	N	m3	

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Practice N°	City	Description	Factor	Practice Group	Practice Type	Practice	Indicated Service	Vegetated	Water component	Unit	Conversion to m2
28	Helsinki	Biofiltration basin or swale. Bioswales, are gently sloped, planted channels for treating and conveying stormwater. Vegetated swales convey stormwater away from the infrastructure, such as sidewalks, roadways, parking lots, and building foundations. They differ from conventional channelling systems as they combine conveyance with stormwater treatment. In contrast to concrete-lined swales and pipes, vegetated swales slow stormwater velocity, allow for evapotranspiration, and remove debris while enhancing sediment dropout and infiltration. In order to infiltrate stormwater in swales, the soil must be permeable or there can be sandfilterlayers added. A swale does not require any other construction than the surface design, the growth layer and the installation of vegetation. An underground drainage layer is used to convey extra water forward if the soil is not permeable. The drainage layer is constructed at the bottom of the structure. Plants used in the swale should tolerate standing water at the bottom of the swale. Plants should be easily maintained. It would also be good to use a variety of different plant species, in order to establish enduring vegetation.	0.77	Stormwater Management System	Detention, Retention and Infiltration system	Bioswale / Channel	Flood risk reduction	Y	N	m2	
29	Helsinki	Capturing stormwater from impermeable surfaces for use in irrigation or directing it in a controlled manner to permeable vegetated areas	0.20	Stormwater Management System	Water harvesting system	Water harvesting system	Water saving	N	N	m2	
30	Helsinki	Directing stormwater from impermeable surfaces to constructed water features, such as ponds and streams, with flowing water A ditch is a narrow channel dug at the side of a road or field, to hold or convey water away. It is deeper than a swale, but the structure offers similar possibilities for infiltration and detention. A ditch is easy to construct and maintain. However, it is seldom used in densely built areas, as it is visually and functionally difficult to integrate into an urban street or park environment. Stormwater can also be conducted in a stream (that is constructed especially for that purpose). A stream is often wider and meanders more than a ditch. It can also include some natural features such as stones, lush vegetation and shallows to slow down stormwater flow.	0.23	Stormwater Management System	Detention, Retention and Infiltration system	Drainage	Flood risk reduction	N	N	m2	
31	Helsinki	Shading large tree (25 m² each) on the south or southwest side of the building (especially deciduous trees)	0.26	Vegetation Unit	Tree	Canopy Large	Thermal regulation /	Y	N	pcs	25
32	Helsinki	Shading small tree (15 m² each) on the south or southwest side of the building (especially deciduous trees)	0.26	Vegetation Unit	Tree	Canopy Small	Thermal regulation /	Y	N	pcs	15
33	Helsinki	Fruit trees or berry bushes suitable for cultivation (10 m² each)	0.29	Vegetation Unit	Tree	Tree	Urban	Y	N	pcs	10
34	Helsinki	A selection of native species – at least 5 species/100 m²	0.26	Functional Surface / Functional Element	Vegetation	Native Vegetation	Undisturbed nature	Y	N	m2	
35	Helsinki	Tree species native to Helsinki and flowering trees and shrubs – at least 3 species/100 m²	0.26	Vegetation Unit	Tree	Native Vegetation	Undisturbed nature	Y	N	m2	
36	Helsinki	Butterfly meadows or plants with pleasant scent or impressive blooming	0.23	Functional Surface / Functional Element	Vegetation	Strengthen Habitat	Insect/Animal habitat	Y	N	m2	
37	Helsinki	Boxes for urban farming/cultivation	0.17	Functional Surface / Functional Element	Area / Space	Cultivation	Urban Agriculture/Food	Y	N	m2	
38	Helsinki	Permeable surface designated for play or sports (e.g. sand- or gravel-covered playgrounds, sports turf)	0.20	Functional Surface / Functional Element	Area / Space	Recreation	Recreation	N	N	m2	
39	Helsinki	Communal rooftop gardens or balconies with at least 10% of the total area covered by vegetation	0.17	Functional Surface / Functional Element	Area / Space	Communal (Rooftop or Balcony)	Social Cohesion	Y	N	m2	
40	Helsinki	Structures supporting natural and/or animal living conditions such as preserved dead wood/stumps or birdboxes (5 m² each)	0.34	Hosting Unit	Animal/Bug hosting structure	Birdbox	Insect/Animal habitat	N	N	pcs	5

APPENDIX 1 - ANALYSIS OF PRACTICES AND ECOSYTEM SERVICES INCLUDED IN EXISTING GARS

Practice N°	City	Description	Factor	Practice Group	Practice Type	Practice	Indicated Service	Vegetated	Water component	Unit	Conversion to m2
41	Seattle	Approved water features	0.70	Surface System	Water body	Fountain	Not Explicit	N	Y	m2	
42	Seattle	Permeable paving over at least 6" and less than 24" of soil or gravel	0.20	Surface System	Permeable surface	(Block) With joints	Not Explicit	N	N	m2	
43	Seattle	Permeable paving over at least 24" of soil or gravel	0.50	Surface System	Permeable surface	(Block) With joints	Not Explicit	N	N	m2	
44	Seattle	Structural soil systems, including CU-Structural Soil, Silva Cells, and their performance equivalents, support pavement while avoiding subsurface compaction, allowing air and water infiltration and contributing to larger, healthier plants. For Green Factor credit, these systems must be at least 24 inches deep, under pavement, and adjacent to planting areas. Credit is calculated by the square footage of the system's footprint. Structural soil systems in the right-of-way must be approved by SDOT. In accordance with SMC 23.86.019, permeable paving and structural soil together cannot add up to more than one third of a site's Green Factor score.	0.20	Vegetation Unit	Tree	Tree	Flood risk reduction	Y	N	m2	
45	Seattle	Drought tolerant or native plant species	0.10	Functional Surface / Functional Element	Vegetation	Drought-tolerance	Water saving	Y	N	m2	
46	Seattle	Landscaped areas where at least 50% of annual irrigation needs are met through the use of harvested water	0.20	Functional Surface / Functional Element	Improved Irrigation	From harvested water	Water saving	Y	N	m2	
47	Seattle	Landscaping visible to passersby from adjacent public right of way or public open spaces	0.10	Functional Surface / Functional Element	Vegetation	Ornamental / Visible	Aesthetic	Y	N	m2	
48	Seattle	Landscaping in food cultivation	0.10	Functional Surface / Functional Element	Area / Space	Cultivation	Urban Agriculture/Food	Y	N	m2	
49	Southampton	Building surface area with no green roof	0.00	Surface System	Impermeable surface	Roof surface	Not Explicit	N	N	m2	
50	Southampton	Extensive green roofs minimal planting depths (as shallow as 2.0 cm) and sometimes only a mineral substrate. They are limited to flowers, grasses, mosses, and drought tolerant succulents such as Sedum, chosen for their ability to regenerate and maintain themselves over long periods of time, in addition to being able to withstand the harsh conditions of cold, heat, drought and wind. Native species are often preferred. Extensive green roofs require minimal maintenance, and are generally not accessible to the public. They do not necessarily require irrigation, and they have fewer other requirements, such as guardrails. Extensive green roofs are the least expensive form of roof greening to implement and maintain. There is much lower human access.	0.60	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
51	Southampton	Intensive Green roofs Intensive green roofs use a wide variety of plant species that may include trees and shrubs, require deeper substrate layers, are generally limited to flat roofs, require 'intense' maintenance, and are often park-like areas accessible to the general public. Intensive green roofs are more costly than extensive green roofs to build and maintain.	0.70	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
52	Southampton	Non-permeable surfaces e.g. tarmac	0.00	Surface System	Impermeable surface	Asphalt	Not Explicit	N	N	m2	
53	Southampton	Permeable paving Stone paving with joints where water can infiltrate	0.20	Surface System	Permeable surface	(Block) With joints	Not Explicit	N	N	m2	
54	Southampton	Semi-permeable surfaces e.g. sand and gravel	0.40	Surface System	Permeable surface	Sand	Not Explicit	N	N	m2	
55	Southampton	Grassland (short, amenity)	0.40	Surface System	Permeable surface	Lawn	Not Explicit	Y	N	m2	
56	Southampton	Grassland (long, rough) Rough grassland that is not being cut regularly. Predominantly grasses but may contain other plants. Natural and amenity grasslands can be found on deep soils, however this likely to be of little use for surface water management as the water's path into the soil is blocked by a dense root mat occurring within the top 5-10cm of soil.	0.50	Surface System	Permeable surface	Grassland	Not Explicit	Y	N	m2	

APPENDIX 1 - ANALYSIS OF PRACTICES AND ECOSYTEM SERVICES INCLUDED IN EXISTING GARS

Practice N°	City	Description	Factor	Practice Group	Practice Type	Practice	Indicated Service	Vegetated	Water component	Unit	Conversion to m2
57	Southampton	Shrubs Vegetation where soil depth is more than 60cm and there is no direct contact with deeper soil e.g. roof of underground parking	0.60	Vegetation Unit	Shrub	Shrub	Not Explicit	Y	N	m2	
58	Southampton	Trees on shallow soil/tree pits Individual landscaping trees in built up spaces e.g. car parks, highway. Area taken as area of canopy.	0.60	Vegetation Unit	Tree	Tree	Not Explicit	Y	N	m2	
59	Southampton	Woodland / trees on deeper soil Vegetation where plants have direct contact with deeper soil. Trees and shrubs, have a more open net-work of surface roots plus bigger, deeper roots which channel water into the soil. Water can therefore percolate into the ground more easily and run down the stem and roots; in this case deep soil is useful because it can hold more water than shallow soil.	1.00	Vegetation Unit	Tree	Tree	Not Explicit	Y	N	m2	
60	Southampton	Open water	1.00	Surface System	Water body	Open water	Not Explicit	N	Y	m2	
61	Southampton	Green Walls with a height limit of 10 metres (area of)	0.60	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
62	Berlin	Sealed surfaces Surface is impermeable to air and water and has no plant growth (e.g., concrete, asphalt, slabs with a solid subbase)	0.00	Surface System	Impermeable surface	Waterproofing	Not Explicit	N	N	m2	
63	Berlin	Partially sealed surfaces Surface is permeable to water and air; as a rule, no plant growth (e.g., clinker brick, mosaic paving, slabs with a sand or gravel subbase)	0.30	Surface System	Permeable surface	(Block) With joints	Not Explicit	N	N	m2	
64	Berlin	Semi-open surfaces Surface is permeable to water and air, water infiltration and plant growth (e.g., gravel with grass, wooden cobbles, grass paving blocks)	0.50	Surface System	Permeable surface	Block Grass	Not Explicit	Y	N	m2	
65	Berlin	Surfaces with vegetation, unconnected to the soil below Surfaces with vegetation that have no connection to the ground and less than 80 cm of soil covering	0.50	Functional Surface / Functional Element	Soil	Shallow soil	Not Explicit	Y	N	m2	
66	Berlin	Surfaces with vegetation, unconnected to the soil below Surfaces with vegetation that have no connection to the ground but more than 80 cm of soil covering	0.70	Functional Surface / Functional Element	Soil	Deep soil	Not Explicit	Y	N	m2	
67	Berlin	Surfaces with vegetation, connected to the soil below Vegetation connected to soil below, available for development of flora and fauna	1.00	Functional Surface / Functional Element	Soil	Open soil	Not Explicit	Y	N	m2	
68	Berlin	Rainwater infiltration per m2 of roof area Rainwater infiltration for replenishment of groundwater; infiltration over surfaces with existing vegetation	0.20	Stormwater Management System	Detention, Retention and Infiltration system	Detention, Retention and Infiltration system	Flood risk reduction	Y	N	m2	
69	Berlin	Vertical greenery with connection to the ground. Direct connection of the vertical greenery with the soil, supply with nutrients and water directly over the roots in the soil	0.50	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
70	Berlin	Vertical greenery without connection to the ground. Vertical or horizontal vegetation on a wall without direct connection to soil on the ground, permanent planters supplying the vegetation areas, artificial irrigation	0.70	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
71	Berlin	Extensive roof greening. Nature-like design of the roof surfaces with a substrate thickness < 20 cm without artificial irrigation	0.50	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
72	Berlin	Semi-intensive roof greening. Mixture of extensive and intensive roof greening with a substrate thickness › 12 cm (depending on the chosen plantings), usually in combination with artificial irrigation	0.70	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
73	Berlin	Intensive roof greening. Design of the roof similar to ground-based green areas with a substrate thickness › 15 cm, usually in combination with artificial irrigation	0.80	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
74	Malmö	Semi-open to open hardened surfaces (stoneware surface)	0.40	Surface System	Permeable surface	(Block) With joints	Not Explicit	N	N	m2	
75	NWE	Buildings (without green roofs)	0.00	Surface System	Impermeable surface	Roof surface	Not Explicit	N	N	m2	

APPENDIX 1 - ANALYSIS OF PRACTICES AND ECOSYTEM SERVICES INCLUDED IN EXISTING GARS

Practice N°	City	Description	Factor	Practice Group	Practice Type	Practice	Indicated Service	Vegetated	Water component	Unit	Conversion to m2
76	NWE	Buildings (with green roofs). N.B. Please only include the area of the roof that is covered by vegetation here, if part of the roof is not vegetated include it in A1).	0.70	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
77	NWE	Non-permeable road surfaces	0.00	Surface System	Impermeable surface	Road / Path	Not Explicit	N	N	m2	
78	NWE	Non-permeable footpath surfaces	0.00	Surface System	Impermeable surface	Road / Path	Not Explicit	N	N	m2	
79	NWE	Non-permeable parking / driveway surfaces	0.00	Surface System	Impermeable surface	Road / Path	Not Explicit	N	N	m2	
80	NWE	Semi-permeable surfaces such as stone paving with joints (where water can infiltrate)	0.20	Surface System	Permeable surface	(Block) With joints	Flood risk reduction	N	N	m2	
81	NWE	Semi-permeable surfaces such as gravel	0.40	Surface System	Permeable surface	Gravel	Not Explicit	N	N	m2	
82	NWE	Vegetated or open soil surfaces (where plants have direct contact with deeper soil)	1.00	Functional Surface / Functional Element	Soil	Open soil	Not Explicit	Y	N	m2	
83	NWE	Vegetated or open soil surfaces (where soil depth is more than 60cm but there is no direct contact with deeper soil; e.g. roof of underground parking). N.B. Please do not use this for green roofs on buildings - use A2 instead.	0.60	Functional Surface / Functional Element	Soil	Deep soil	Not Explicit	Y	N	m2	
84	NWE	Vegetated or open soil surfaces (where soil depth is less than 60cm and there is no direct contact with deeper soil; e.g. roof of underground parking). N.B. Please do not use this for green roofs on buildings - use A2 instead.	0.40	Functional Surface / Functional Element	Soil	Shallow soil	Not Explicit	Y	N	m2	
85	NWE	Open water surfaces (including ponds and swales covered by water for at least 6 months of the year)	1.00	Surface System	Water body	Open water	Not Explicit	N	Y	m2	
86	NWE	Shrubs and hedges. N.B. Should not exceed development site area. Can overlap surfaces A1-D and F.	0.30	Vegetation Unit	Shrub	Shrub	Not Explicit	Y	N	m2	
87	NWE	Trees (canopy cover area). N.B. Should not exceed development site area. Can overlap surfaces A1-D and E.	0.40	Vegetation Unit	Tree	Tree	Not Explicit	Y	N	m2	
88	NWE	Green walls (area up to a height limit of 10 m)	0.60	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
89	Seattle	Landscaped areas with a soil depth of less than 24" (approx. 60cm)	0.10	Functional Surface / Functional Element	Soil	Deep soil	Not Explicit	Y	N	m2	
90	Seattle	Landscaped areas with a soil depth of 24" (approx. 60cm) or greater	0.60	Functional Surface / Functional Element	Soil	Open soil	Not Explicit	Y	N	m2	
91	Seattle	Bioretention facilities	1.00	Stormwater Management System	Detention, Retention and Infiltration system	Detention, Retention and Infiltration system	Flood risk reduction	Y	N	m2	
92	Seattle	Mulch, ground covers or other plants less than 2" tall at maturity	0.10	Surface System	Permeable surface	Mulch	Not Explicit	N	N	m2	
93	Seattle	Shrubs or perennials, 2'+ at maturity - calculated at 12 sq ft per plant (typically planted no closer than 18" on centre)	0.30	Vegetation Unit	Shrub	Shrub	Not Explicit	Y	N	pcs	1.11
94	Seattle	Tree canopy for "small trees" or equivalent (canopy spread 8' to 15', approx. 2.4 to 4.5m) - calculated at 75sq ft (approx. 7m²) per tree	0.30	Vegetation Unit	Tree	Canopy Small	Not Explicit	Y	N	pcs	6.97
95	Seattle	Tree canopy for "small/medium trees" or equivalent (canopy spread 16' to 20', approx. 4.8 to 6.1 m) - calculated at 150sq ft (approx. 14m²) per tree	0.30	Vegetation Unit	Tree	Canopy Small	Not Explicit	Y	N	pcs	13.94
96	Seattle	Tree canopy for "medium/large trees" or equivalent (canopy spread 21' to 25', approx. 6.4 to 7.6 m) - calculated at 250sq ft (approx. 23m²) per tree	0.40	Vegetation Unit	Tree	Canopy Medium	Not Explicit	Y	N	pcs	23.23
97	Seattle	Tree canopy for "large trees" or equivalent (canopy spread 26' to 30', approx. 7.9 to 11.9m) - calculated at 350sq ft (approx. 32.5m²) per tree	0.40	Vegetation Unit	Tree	Canopy Large	Not Explicit	Y	N	pcs	32.52
98	Seattle	Tree canopy for preservation of large existing trees with trunks 6" (approx. 15cm) in diameter - calculated at 20 sq ft (approx. 1.9m²) per inch diameter	0.80	Vegetation Unit	Tree	Tree	Undisturbed nature	Y	N	per inch diamet	1.86
99	Seattle	Green roofs - over at least 2" and less than 4" of growth medium	0.40	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
100	Seattle	Green roofs - over at least 4" of growth medium	0.70	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	

APPENDIX 1 - ANALYSIS OF PRACTICES AND ECOSYTEM SERVICES INCLUDED IN EXISTING GARS

Practice N°	City	Description	Factor	Practice Group	Practice Type	Practice	Indicated Service	Vegetated	Water component	Unit	Conversion to m2
101	Seattle	Vegetated walls	0.70	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
102	Stockholm	Preserved natural land Existing trees can be used as an additional factor	1.50	Functional Surface / Functional Element	Vegetation	Preserved Vegetation	Undisturbed nature	Y	N	m2	
103	Stockholm	Greenery on the ground level	1.50	Functional Surface / Functional Element	Vegetation	Ornamental / Visible	Not Explicit	Y	N	m2	
104	Stockholm	Plant bed> 800 mm deep	1.40	Functional Surface / Functional Element	Soil	Open soil	Not Explicit	Y	N	m2	
105	Stockholm	Plant bed 600-800 mm deep	0.30	Functional Surface / Functional Element	Soil	Shallow soil	Not Explicit	Y	N	m2	
106	Stockholm	Plant bed 200-600 mm deep	0.10	Functional Surface / Functional Element	Soil	Shallow soil	Not Explicit	Y	N	m2	
107	Stockholm	Green roof with> 300 mm deep plant bed	0.30	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
108	Stockholm	Green roof with 110-300 mm deep plant bed	0.10	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
109	Stockholm	Green roof with 50 - 110 mm deep plant bed	0.05	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
110	Stockholm	Greenery on walls	0.40	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
111	Stockholm	Lush balconies	0.30	Functional Surface / Functional Element	Soil	Shallow soil	Not Explicit	Y	N	m2	
112	Stockholm	Diversity in the vegetation layer Diversity places higher demand on maintenance	0.05	Functional Surface / Functional Element	Vegetation	Diversity of Vegetation	Diversity	Y	N	m2	
113	Stockholm	Native species selection	0.50	Functional Surface / Functional Element	Vegetation	Native Vegetation	Undisturbed nature	Y	N	m2	
114	Stockholm	Diversity on green thin sedum roofs A variety of species on the green roof can attract butterflies and other insects	0.10	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Diversity	Y	N	m2	
115	London	Water features (chlorinated) or unplanted detention basins	0.20	Stormwater Management System	Detention, Retention and Infiltration system	Basin/Reservoir/Pond	Flood risk reduction	N	N	m2	
116	London	Permeable paving - see CIRIA for overview	0.10	Surface System	Permeable surface	Permeable pavers	Not Explicit	N	N	m2	
117	London	Sealed surfaces (e.g. concrete, asphalt, waterproofing, stone)	0.00	Surface System	Impermeable surface	Concrete	Not Explicit	N	N	m2	
118	Malmö	Greenery on the ground	1.00	Functional Surface / Functional Element	Vegetation	Ornamental / Visible	Not Explicit	Y	N	m2	
119	Malmö	Green roofs - Plant bed on floor 40-80mm depth 0.4	0.40	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
120	Malmö	Plant bed on floor level 80-200mm deep	0.60	Functional Surface / Functional Element	Soil	Shallow soil	Not Explicit	Y	N	m2	
121	Malmö	Plant bed at floor level 200-800mm deep	0.70	Functional Surface / Functional Element	Soil	Shallow soil	Not Explicit	Y	N	m2	
122	Malmö	Plant bed on floor level> = 800mm deep	0.90	Functional Surface / Functional Element	Soil	Open soil	Not Explicit	Y	N	m2	
123	Malmö	Greenery on walls	0.70	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
124	Malmö	accumulated points for trees		Vegetation Unit	Tree	Tree	Not Explicit	Y	N	m2	various
125	Malmö	Accumulated points for bushes, hedges and ground covers		Vegetation Unit	Shrub	Shrub	Not Explicit	Y	N	m2	various
126	Malmö	Water surfaces	1.00	Surface System	Water body	Water body	Not Explicit	N	Y	m2	
127	Malmö	Collection and retention of stormwater	0.20	Stormwater Management System	Water harvesting system	Water harvesting system	Not Explicit	N	N	m2	
128	Malmö	Drainage of sealed and hardened surfaces to surrounding greenery on the ground	0.20	Stormwater Management System	Detention, Retention and Infiltration system	Drainage	Flood risk reduction	N	N	m2	
129	Malmö	Sealed surfaces	0.00	Surface System	Impermeable surface	Impermeable surface	Not Explicit	N	N	m2	
130	Malmö	Paved surfaces with joints (concrete stone surface, wooden deck)	0.20	Surface System	Permeable surface	(Block) With joints	Not Explicit	N	N	m2	
131	Stockholm	Lush balconies with hanging or climbing plants	0.30	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	

APPENDIX 1 - ANALYSIS OF PRACTICES AND ECOSYTEM SERVICES INCLUDED IN EXISTING GARS

Practice N°	City	Description	Factor	Practice Group	Practice Type	Practice	Indicated Service	Vegetated	Water component	Unit	Conversion to m2
132	Stockholm	Vegetation that attracts butterflies	1.00	Functional Surface / Functional Element	Vegetation	Strengthen Habitat	Insect/Animal Habitat	Y	N	m2	
133	Stockholm	Shrubs in general	0.20	Vegetation Unit	Shrub	Shrub	Not Explicit	Y	N	m2	
134	Stockholm	Bearing shrubs	0.40	Vegetation Unit	Shrub	Shrub	Urban Agriculture/Food	Y	N	m2	
135	Stockholm	Natural trees (specified in the GYF template)	3.00	Vegetation Unit	Tree	Tree	Not Explicit	Y	N	pcs	25
136	Stockholm	Existing trees	3.00	Vegetation Unit	Tree	Tree - Preserved	Undisturbed nature	Y	N	pcs	50
137	Stockholm	New large trees (stem> 30 cm)	2.40	Vegetation Unit	Tree	Tree	Not Explicit	Y	N	pcs	25
138	Stockholm	New medium-sized trees (stem 20-30 cm)	1.50	Vegetation Unit	Tree	Tree	Not Explicit	Y	N	pcs	25
139	Stockholm	New small trees (stem 16-20 cm)	1.00	Vegetation Unit	Tree	Tree	Not Explicit	Y	N	pcs	25
140	Stockholm	Bearing trees	0.40	Vegetation Unit	Tree	Tree	Urban Agriculture/Food	Y	N	pcs	25
141	Stockholm	Birdhouses nest hives	0.50	Hosting Unit	Animal/Bug hosting structure	Birdbox	Insect/Animal Habitat	N	N	pcs	5
142	Stockholm	Bug feeders Specially made wooden pockets with food should be placed in relative proximity to existing natural environments	2.00	Hosting Unit	Animal/Bug hosting structure	Bug feeder	Insect/Animal Habitat	N	N	pcs	5
143	Stockholm	Fauna depots Dead branches from old trees are important for among, woord-borne insects and fungi	2.00	Hosting Unit	Animal/Bug hosting structure	Branches	Insect/Animal Habitat	N	N	pcs	5
144	Stockholm	Biological design elements / habitat enhancement measures. Traffic safe passage designed appropriately so that the breeding animals can get under the road or the street	2.00	Surface System	Eco-bridge / Faunal passage	Eco-bridge / Faunal passage	Insect/Animal Habitat	Y	N	pcs	5
145	Stockholm	Areas for social activity	1.20	Functional Surface / Functional Element	Area / Space	Social	Social Cohesion	N/A	N	m2	
146	Stockholm	Cultivation Areas	0.50	Functional Surface / Functional Element	Area / Space	Cultivation	Urban Agriculture/Food provision	Y	N	m2	
147	Stockholm	Roofs, balconies, terraces and greenhouses for cultivation	0.50	Functional Surface / Functional Element	Area / Space	Cultivation	Urban Agriculture/Food provision	Y	N	m2	
148	Stockholm	Common roof terraces	0.20	Functional Surface / Functional Element	Area / Space	Communal (Terrace)	Social Cohesion	N/A	N	m2	
149	Stockholm	Visible green roofs	0.05	Functional Surface / Functional Element	Vegetated Surface	Ornamental / Visible (Green roof)	Aesthetic	Y	N	m2	
150	Stockholm	Flowers in the vegetation layer It provides beauty and garden character to the surface	0.20	Functional Surface / Functional Element	Vegetation	Ornamental / Visible	Aesthetic	Y	N	m2	
151	Stockholm	Bushes experience/impression values	0.10	Vegetation Unit	Shrub	Shrub	Recreation	Y	N	m2	
152	Stockholm	Shrubs with edible berries and fruits	0.20	Vegetation Unit	Shrub	Shrub	Urban Agriculture/Food	Y	N	m2	
153	Stockholm	Trees, experience values	0.40	Vegetation Unit	Tree	Tree	Recreation	Y	N	pcs	25
154	Stockholm	Fruit trees	0.20	Vegetation Unit	Tree	Tree	Urban Agriculture/Food	Y	N	pcs	25
155	Stockholm	Pergolas or structures for vertical and horizontal greenery contribute to spatially and visual shielding	0.30	Shading Unit	Shading measure / structure	Shading Structure	Aesthetic	Y	N	m2	
156	Stockholm	Habitat strengthening measures, experience values A rich biological life improves the garden environment. Here the children can closely follow the different phases of nature. The farm is supplied with natural educational values	0.20	Functional Surface / Functional Element	Area / Space	Accessibility / Experimental	Recreation	Y	N	pcs	5
157	Stockholm	Trees placed so that they provide temporary shade	0.40	Vegetation Unit	Tree	Tree	Thermal regulation / Shade	Y	N	pcs	25
158	Stockholm	Pergolas, deciduous leaves, etc. that provide temporary shade	0.50	Shading Unit	Shading measure / structure	Shading Structure	Thermal regulation / Shade	Y	N	m2	
159	Stockholm	Green roofs or multi-layered greenery	0.05	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	

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Practice N°	City	Description	Factor	Practice Group	Practice Type	Practice	Indicated Service	Vegetated	Water component	Unit	Conversion to m2
160	Stockholm	Vegetation-covered land	0.10	Surface System	Permeable surface		Not Explicit	Y	N	m2	
161	Stockholm	Greenery on walls, plant substrate on the wall	0.30	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
162	Stockholm	Greenery on walls, climbing plants	0.10	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
163	Stockholm	Green roofs	0.05	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
164	Stockholm	Water surfaces in ponds, streams and ditches	1.00	Surface System	Water body	Pond	Not Explicit	N	Y	m2	
165	Stockholm	Open hardened surfaces (concrete or natural stone tiles that have grass between them)	0.30	Surface System	Permeable surface	(Block) With joints	Not Explicit	N	N	m2	
166	Stockholm	Semi-open hardened surfaces (open asphalt, gravel, sand, and other surfaces with high permeability for stormwater)	0.20	Surface System	Permeable surface	High permeability	Flood risk reduction	N	N	m2	
167	Stockholm	Hard surfaces with joints (concrete slabs, paving stones, and tiles, with normal joints such as sand would give a certain permeability to the stormwater)	0.05	Surface System	Permeable surface	(Block) With joints	Flood risk reduction	N	N	m2	
168	Stockholm	Dense surfaces (Roof surfaces, and concrete that does not have any form of plant basin or other opportunities to develop a biological environment for vegetation)	0.00	Surface System	Impermeable surface	Roof surface	Not Explicit	N	N	m2	
169	Stockholm	Biological water surfaces in ponds, streams and the ditches inside the yard. Existing during spring and summer. Contributes to richer wildlife (insects, birds and others)	4.00	Surface System	Water body	Pond	Insect/Animal Habitat	N	Y	m2	
170	Stockholm	Moisture with temporary lingering water Vegetation surfaces that holds water temporarily during parts of the summer months, up to 6 months. This contributes to richer wildlife (insects, birds and other species)	2.00	Stormwater Management System	Detention, Retention and Infiltration system	Basin/Reservoir/Pond	Insect/Animal Habitat	Y	Y	m2	
171	Stockholm	Stormwater retention delay Drainage from impermeable surfaces (factor 0 and 0.05) that are collected in ponds or moisture paths. It helps create local water environments with ponds, moisture stretches, etc. which has impact on plant and animal life.	0.20	Stormwater Management System	Detention, Retention and Infiltration system	Basin/Reservoir/Pond	Flood risk reduction	N	N	m2	
172	Stockholm	Dewatering hard surfaces to surrounding greenery on ground level.	0.20	Stormwater Management System	Detention, Retention and Infiltration system	Drainage	Flood risk reduction	N	N	m2	
173	Stockholm	Delay of stormwater from hard surfaces in reservoirs	0.10	Stormwater Management System	Detention, Retention and Infiltration system	Basin/Reservoir/Pond	Flood risk reduction	N	N	m2	
174	Stockholm	Water Mirrors / reflective water Reflect light and is aesthetic	0.50	Surface System	Water body	Water body	Aesthetic	N	Y	m2	
175	Stockholm	Biologically accessible water - experience values and available for animal and plant life	1.00	Surface System	Water body	Water body	Recreation	N	Y	m2	
176	Stockholm	Fountains and the like. Sound of water contribute to the park's attractiveness. Circulation of the water also contribute to oxygenation	0.30	Surface System	Water body	Fountain	Aesthetic	N	Y	pcs	25
177	Stockholm	Water collections for dry periods. The need for cooling increases with more and longer heat waves. Water in various forms contributes to the coolness of parks	0.50	Stormwater Management System	Water harvesting system	Water harvesting system	Thermal regulation / Cooling from water	N	Y	m2	
178	Stockholm	Collection of rainwater in reservoir for irrigation for later use in drought provides additional points	0.05	Stormwater Management System	Water harvesting system	Water harvesting system	Water saving	N	N	m2	
179	Stockholm	Fountains and the like. Higher humidity and the sound of water contribute to both real and anticipated coolness during hot summer days.	0.30	Surface System	Water body	Fountain	Thermal regulation / Cooling from water	N	Y	pcs	25
180	Stockholm	Fountains and the like. Water sounds can cover unwanted noise and contribute to a better sound environment in gardens.	0.30	Surface System	Water body	Fountain	Noise reduction	N	Y	pcs	25

APPENDIX 1 - ANALYSIS OF PRACTICES AND ECOSYTEM SERVICES INCLUDED IN EXISTING GARS

Practice N°	City	Description	Factor	Practice Group	Practice Type	Practice	Indicated Service	Vegetated	Water component	Unit	Conversion to m2
181	Washington DC	Landscaped areas with a soil depth of less than 24" (approx. 60cm)	0.30	Functional Surface / Functional Element	Soil	Deep soil	Not Explicit	Y	N	m2	
182	Washington DC	Landscaped areas with a soil depth greater or same as 24" (approx. 60cm)	0.60	Functional Surface / Functional Element	Soil	Shallow soil	Not Explicit	Y	N	m2	
183	Washington DC	Bioretention facilities	0.40	Stormwater Management System	Detention, Retention and Infiltration system	Detention, Retention and Infiltration system	Flood risk reduction	Y	N	m2	
184	Washington DC	Groundcovers or other plants less than 2" height (approx. 5cm)	0.20	Surface System	Vegetated Surface	Groundcover	Not Explicit	Y	N	m2	
185	Washington DC	Plants greater or same as 2" (approx.. 5cm) height at maturity - calculated at 50 sq ft (approx. 4.6m2) per tree	0.30	Functional Surface / Functional Element	Soil	Shallow soil	Not Explicit	Y	N	pcs	
186	Washington DC	New trees with less than 40-foot (approx. 12.2m) canopy spread - calculated at 50 sq ft (approx. 4.6m²) per tree	0.50	Vegetation Unit	Tree	Canopy Medium	Not Explicit	Y	N	pcs	
187	Washington DC	New trees with 40-foot (12.2m) or greater canopy spread - calculated at 250 sq ft (approx. 23m²) per tree	0.60	Vegetation Unit	Tree	Canopy Large	Not Explicit	Y	N	pcs	
188	Washington DC	Preservation of existing tree 6" to 12" (approx. 15 to 30cm) DBH - calculated at 250 sq ft (approx. 23m²) per tree	0.70	Vegetation Unit	Tree	Tree - Preserved	Undisturbed nature	Y	N	pcs	
189	Washington DC	Preservation of existing tree 12" to 18" (approx. 30 to 46cm) DBH - calculated at 600 sq ft (approx. 56m²) per tree	0.70	Vegetation Unit	Tree	Tree - Preserved	Undisturbed nature	Y	N	pcs	
190	Washington DC	Preservation of existing trees 18" to 24" (approx. 46 to 60cm) DBH - calculated at 1300 sq ft (approx.121m²) per tree	0.70	Vegetation Unit	Tree	Tree - Preserved	Undisturbed nature	Y	N	pcs	
191	Washington DC	Preservation of existing trees 24" (approx.60cm) DBH or greater - calculated at 2000 sq ft (approx. 186m²) per tree	0.80	Vegetation Unit	Tree	Tree - Preserved	Undisturbed nature	Y	N	pcs	
192	Washington DC	Vegetated wall, plantings on a vertical surface	0.60	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
193	Washington DC	Vegetated or green roofs - Over at least 2" (approx.. 5cm) and less than 8" (approx.. 20cm) growth medium	0.60	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
194	Washington DC	Vegetated or green roofs - Over at least 8" (approx.. 20cm) of growth medium	0.80	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
195	Washington DC	Permeable paving over 6" (approx.. 15cm) to 24" (approx.. 30cm) of soil or gravel	0.40	Surface System	Permeable surface	Permeable pavers	Not Explicit	N	N	m2	
196	Washington DC	Permeable paving over at least 24" (approx. 30cm) of soil or gravel	0.50	Surface System	Permeable surface	Permeable pavers	Not Explicit	N	N	m2	
197	Washington DC	Enhanced tree growth systems. Permeable paving and structural soil together may not qualify for more than one third of the Green Area Ratio score.	0.40	Vegetation Unit	Tree	Tree	Undisturbed nature	Y	N	m2	
198	Washington DC	Renewable energy generation	0.50	Functional Surface / Functional Element	Area / Space	Technical	Clean energy	N/A	N	m2	
199	Washington DC	Approved water features	0.20	Surface System	Water body	Fountain	Not Explicit	N	Y	m2	
200	Washington DC	Native plant species	0.10	Functional Surface / Functional Element	Vegetation	Native Vegetation	Undisturbed nature	Y	N	m2	
201	Washington DC	Landscaping in food cultivation	0.10	Functional Surface / Functional Element	Area / Space	Cultivation	Urban Agriculture/Food provision	Y	N	m2	
202	Washington DC	Harvested stormwater irrigation	0.10	Stormwater Management System	Water harvesting system	Water harvesting system	Water saving	N	N	m2	
203	London	Semi-natural vegetation (e.g. woodland, flower-rich grassland) created on site	1.00	Surface System	Permeable surface		Not Explicit	Y	N	m2	
204	London	Wetland or open water (semi-natural; not chlorinated) created on site	1.00	Surface System	Water body	Wetland	Not Explicit	Y	Y	m2	
205	London	Intensive green roof or vegetation over structure. Vegetated sections only. Substrate minimum settled depth of 150mm – See livingroofs.org for descriptions.	0.80	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
206	London	Standard trees planted in natural soils or in connected tree pits with a minimum soil volume equivalent to at least two-thirds of the projected canopy area of the mature tree -see Trees in Hard Landscapes for overview.	0.80	Vegetation Unit	Tree	Tree	Not Explicit	Y	N	m2	

APPENDIX 1 - ANALYSIS OF PRACTICES AND ECOSYTEM SERVICES INCLUDED IN EXISTING GARS

Practice N°	City	Description	Factor	Practice Group	Practice Type	Practice	Indicated Service	Vegetated	Water component	Unit	Conversion to m2
207	London	Extensive green roof with substrate of minimum settled depth 80mm (or 60mm beneath vegetation blanket) – meets the requirements of GRO Code 2014.46	0.70	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	
208	London	Flower-rich perennial planting – see Centre for Designed Ecology.	0.70	Vegetation Unit	Shrub	Shrub	Not Explicit	Y	N	m2	
209	London	Rain gardens and other vegetated sustainable drainage elements – See CIRIA for case studies.	0.70	Stormwater Management System	Detention, Retention and Infiltration system	Raingarden	Flood risk reduction	Y	N	m2	
210	London	Hedges (line of mature shrubs one or two shrubs wide) – see RHS for guidance	0.60	Vegetation Unit	Shrub	Shrub	Not Explicit	Y	N	m2	
211	London	Standard trees planted in pits with soil volumes less than two thirds less than the projected canopy area of the mature tree.	0.60	Vegetation Unit	Tree	Tree	Not Explicit	Y	N	m2	
212	London	Green wall – modular system or climbers rooted in soil – see NBS Guide to Façade Greening for overview.	0.60	Surface System	Vegetated Surface	Green wall	Not Explicit	Y	N	m2	
213	London	Groundcover planting – see RHS Groundcover Plants for overview	0.50	Surface System	Vegetated Surface	Groundcover	Not Explicit	Y	N	m2	
214	London	Amenity grassland (species-poor, regularly mown lawns)	0.40	Surface System	Permeable surface	Lawn	Not Explicit	Y	N	m2	
215	London	Extensive green roof of sedum mat or other lightweight systems that do not meet GRO Code 2014	0.30	Stormwater Management System	Detention, Retention and Infiltration system	Green roof	Not Explicit	Y	N	m2	

APPENDIX 2 - ANALYSIS OF PRACTICES AND INDICATED ECOSYSTEM SERVICES IN LOCAL BUILDING REGULATIONS

									Regulating					Provisioning			Cultural			Supporting		
Source	**Type**	**Voluntary**	**Origin**	**Year**	**Name**	**Credit / Section**	**ID N°**	**Suggested practice**	Thermal regulation (Reduced Urban Heat Island	Thermal Regulation (Provision of Shade)	Reduced Air Pollution	Flood risk reduction	Noise reduction	Urban Agriculture / Food Provision	Clean energy	Water Saving	Aesthetic / Visual Interest	Recreation	Social cohesion	Undisturbed nature	Insect Animal / Habitat	Diversity
Leadership in Energy and Environmental Design v4.1	Certification	Y	United States	2019	LEED v4.1 Building Design and Construction	WE Prerequisite: Outdoor Water Use Reduction	1	Efficient Irrigation Systems								x						
						WE Outdoor Water Use Reduction	2	Plant Species selection								x						
						SS Heat Island Reduction	3	Pavers with 50% unbound	x													
							4	Reflective Paint / Cool roof	x													
							5	Vegetated structures	x	x												
							6	Paver with high SRI values	x													
							7	Architectural Structures or Devices	x	x												
							8	Energy Generation Systems as shading structures (non-roof measure)	x	x					x							
							9	Shading Plants	x	x												
							10	Energy Generation Systems as shading structures (car parking cover)	x	x					x							
						SS Open Space	11	Garden Area						x					x			
							12	Landscaped Area									x	x	x		x	x
							13	Wetlands									x					
							14	Green roof - Extensive or Intensive										x	x			
							15	Pedestrian-oriented pavers											x			
							16	Recreation oriented pavers										x				
						SS Protect or Restore Habitat	17	Native or Adapted vegetation												x		
						SS Rainwater Management	18	Green roofs				x										
							19	Permeable Surfaces				x										
							20	Permanent infiltration or collection features (e.g. vegetated swales)				x										
							21	Rain garden				x										
							22	Rainwater cistern				x										
							23	Detention or retention ponds				x										
							24	Pipes				x										
							25	Vaults				x										

APPENDIX 2 - ANALYSIS OF PRACTICES AND INDICATED ECOSYSTEM SERVICES IN LOCAL BUILDING REGULATIONS

									Regulating					Provisioning			Cultural			Supporting		
Source	Type	Voluntary	Origin	Year	Name	Credit / Section	ID N°	Suggested practice	Thermal regulation (Reduced Urban Heat Island	Thermal Regulation (Provision of Shade)	Reduced Air Pollution	Flood risk reduction	Noise reduction	Urban Agriculture / Food Provision	Clean energy	Water Saving	Aesthetic / Visual Interest	Recreation	Social cohesion	Undisturbed nature	Insect Animal / Habitat	Diversity
Excellence in Design for Greater Efficiency	Certification	Y	United States	2019	EDGE version 2.1	E03 - Reflective Paint / Tiles for Roof E04 - Reflective Paint for External Walls	26	Reflective Paint / Cool roof	x													
						W11 - Water Efficient Landscaping	28	Native and adaptive plants								x				x		
							29	Low water-using plants								x						
							30	Drip irrigation or under surface system								x						
Building Research Establishment Environmental Assessment Method	Certification	Y	United Kingdom	2012	BREEAM SD202 - 1.2:2012	S07 Public Realm	31	Landscaped Area										x	x			
						S08 Microclimate	32	Deciduous Trees	x	x												
						S11 Green Infrastructure	33	Green Infrastructure											x			
						LE03 Water Pollution	34	Green Roofs								x						
							35	Permeable Surfaces								x						
						LE04 Enhancement of ecological value	36	Green Infrastructure									x		x		x	x
						LE05 Landscape	37	Native Species								x				x		
						LE 06 Rainwater Harvesting	38	Rainwater collection systems (tank)								x						
						TM 02 Safe appealing streets	39	Landscaped Area									x					
						RE 03 Water Strategy	40	Efficient Irrigation Systems								x						
Supreme Decree N° 010-2018-VIVIENDA	Certification	Y	Peru	2018	MiVivienda Verde	1.0 Water - Rational consumption of Water	41	Water Treatment Plant within the plot								x						
						1.0 Water - Water Reuse	42	Technified irrigation systems								x						
Supreme Decree N° 015-2015-VIVIENDA Prieto, no date	Supreme Decree	Y	Peru	2015	Technical Code of Sustainable Building (Código Técnico de Construcción Sostenible)	Chapter III. Subchapter I - Green areas	43	Xerophytic plants								x						
						Chapter III. Subchapter I - Green areas	44	Native plants								x				x		
						Chapter II. Subchapter IV - Reuse of domestic treated water	45	Water Treatment Plant within the plot								x						
						Chapter II. Subchapter III - Efficient Irrigation Systems	46	Efficient Irrigation Systems								x						

APPENDIX 2 - ANALYSIS OF PRACTICES AND INDICATED ECOSYSTEM SERVICES IN LOCAL BUILDING REGULATIONS

									Regulating					Provisioning			Cultural			Supporting		
Source	**Type**	**Voluntary**	**Origin**	**Year**	**Name**	**Credit / Section**	**ID N°**	**Suggested practice**	Thermal regulation (Reduced Urban Heat Island	Thermal Regulation (Provision of Shade)	Reduced Air Pollution	Flood risk reduction	Noise reduction	Urban Agriculture / Food Provision	Clean energy	Water Saving	Aesthetic / Visual Interest	Recreation	Social cohesion	Undisturbed nature	Insect Animal / Habitat	Diversity
Ordinance N° 510-MM	Ordinance	Y	Peru	2020	Ordenanza que modifica la Ordenanza N° 510/MM, que establece, regula y promueve condiciones para edficaciones sostenibles en el distrito de Miraflores (Ordinance amending Ordinance No. 510 / MM, that establishes, regulates and promotes conditions for sustainable buildings in the Miraflores district)		47	Intensive green roofs			x			x							x	
							48	Tree planting	Purpose not explicitly specified													
							49	Roof (Solar reflectance min. 70%)	Purpose not explicitly specified													
							50	Water Treatment Plant within the plot								x						
							51	Technified irrigation systems (drip irrigation or sprinklers)								x						
							52	Xerophytic plants								x						
							53	Native or adapted plants								x				x		
							54	Artificial Bee Hives													x	
							55	Donation of front yard for public space									x	x	x			
							56	Certification LEED (*)	x	x		x		x	x	x	x	x	x		x	x
							57	Certification EDGE (*)	x							x						
							58	Certification BREEAM (*)	x	x		x				x	x	x	x		x	x
Ordinance N° 437-MSI	Ordinance	N (*)	Peru	2016	Modifican la Ordenanza Nº 412-MSI, que establece disposiciones para incentivar la inversión y la mejora de la competitividad en el distrito (Modify Ordinance No. 412-MSI, which establishes measures to encourage investment and the improvement of competitiveness in the district)		59	Green roof	Purpose not explicitly specified													
Ordinance N° 474-MSI	Regulation	N (*)	Peru	2019	Reglamento Integrado Normativo para el distrito de San Isidro (Integrated Regulations and Norms for the district of San Isidro)		60	Green roof	Purpose not explicitly specified													

APPENDIX 2 - ANALYSIS OF PRACTICES AND INDICATED ECOSYSTEM SERVICES IN LOCAL BUILDING REGULATIONS

									Regulating					Provisioning			Cultural			Supporting		
Source	**Type**	**Voluntary**	**Origin**	**Year**	**Name**	**Credit / Section**	**ID N°**	**Suggested practice**	Thermal regulation (Reduced Urban Heat Island)	Thermal Regulation (Provision of Shade)	Reduced Air Pollution	Flood risk reduction	Noise reduction	Urban Agriculture / Food Provision	Clean energy	Water Saving	Aesthetic / Visual Interest	Recreation	Social cohesion	Undisturbed nature	Insect Animal / Habitat	Diversity
Ordinance N° 623-MSB-2019	Ordinance	Y	Peru	2019	Ordenanza de edificaciones sostenibles en zonas residenciales en el distrito de San Borja (Ordinance of sustainable buildings in residential areas in the district of San Borja)		61	Donation of front yard for public space			x						x	x	x			
							62	Xerophytic plants			x						x					
							63	Native plants			x						x			x		
							64	Tree planting, principally at public space			x						x					
							65	Green roof - Intensive (180 kg/m2), preferably with shrubs and trees			x						x					
							66	Green wall	Purpose not explicitly specified													
							67	Technified irrigation systems			x					x						
							68	Certification LEED (*)	x	x		x		x	x	x	x	x	x		x	x
							69	Certification EDGE (*)	x							x						
							70	Certification BREEAM (*)	x	x		x				x	x	x	x		x	x
Ordinance N° 412-MSI-2015	Ordinance	Y	Peru	2015	Ordenanza que establece disposiciones para incentivar la inversión y la mejora de la competitividad en el distrito (Ordinance that establishes provisions to encourage investment and improve competitiveness in the district)		71	Donation of private area for public space									x	x	x			
Law N° 30102	Law	N	Peru	2013	Ley que dispone medidas preventivas contra los		72	Tree planting		x												
							73	Shading devices		x												
Vice Ministerial Resolution N° 0017-2008-ED	Resolution	N	Peru	2008	Guía De Aplicación De Arquitectura Bioclimática En Locales Educativo (Guide of Bioclimatic Architecture for Educational Buildings)		74	Roof in gardens		x												
Supreme Decree N° 011-2006-VIVIENDA	Supreme Decree	N	Peru	2006	National Building Code (Reglamento Nacional de Edificaciones)		75		No ES referenced except provision of green area and proportion open space													

APPENDIX 2 - ANALYSIS OF PRACTICES AND INDICATED ECOSYSTEM SERVICES IN LOCAL BUILDING REGULATIONS

									Regulating					Provisioning			Cultural			Supporting		
Source	**Type**	**Voluntary**	**Origin**	**Year**	**Name**	**Credit / Section**	**ID N°**	**Suggested practice**	Thermal regulation (Reduced Urban Heat Island	Thermal Regulation (Provision of Shade)	Reduced Air Pollution	Flood risk reduction	Noise reduction	Urban Agriculture / Food Provision	Clean energy	Water Saving	Aesthetic / Visual Interest	Recreation	Social cohesion	Undisturbed nature	Insect Animal / Habitat	Diversity
Supreme Decree N° 004-2011 VIVIENDA	Supreme Decree	N	Peru	2011	Regulation of Territorial Conditioning and Urban Development (Reglamento de Acondicionamiento Territorial y Desarrollo Urbano)		76		No ES referenced except provision of green area and proportion open space													
Supreme Decree N° 022-2016-VIVIENDA	Supreme Decree	N	Peru	2016	Regulation of Territorial Conditioning and Sustainable Urban Development (Reglamento de Acondicionamiento Territorial y Desarrollo Urbano Sostenible)		77		No ES referenced except provision of green area and proportion open space													

(*) Only aspects of certifications relevant to green infrastructure reviewed

APPENDIX 3 - CATEGORISATION OF LOCAL PRACTICES

Practice N°	City	Description	Practice Group	Practice Type	Practice	Vegetated	Water component
1	Lima - sustainable practices	Artificial Bee Hives	Hosting Unit	Animal/Bug hosting structure	Artificial Bee Hives	N	N
2	Lima - other practices	Artificial turf	Surface System	Impermeable surface	Artificial turf	N	N
3	Lima - other practices	Bare concrete	Surface System	Impermeable surface	Bare concrete	N	N
4	Lima - other practices	Bare soil	Surface System	Permeable surface	Bare soil	N	N
5	Lima - sustainable practices	Certification BREEAM (*)	Certification	Building certification	Building certification	N/A	N/A
6	Lima - sustainable practices	Certification EDGE (*)	Certification	Building certification	Building certification	N/A	N/A
7	Lima - sustainable practices	Certification LEED (*)	Certification	Building certification	Building certification	N/A	N/A
8	Lima - sustainable practices	Deciduous Trees	Shading Unit	Shading measure / structure	Tree planting	Y	N
9	Lima - sustainable practices	Detention or retention ponds	Stormwater Management System	Detention, Retention and Infiltration system	Detention or retention ponds	N	Y
10	Lima - sustainable practices	Donation of private area for public space	Functional Surface / Functional Element	Donation of private area for public space	Donation of private area for public space	N/A	N/A
11	Lima - sustainable practices	Drip irrigation or under surface system	Functional Surface / Functional Element	Improved Irrigation	Drip irrigation or under surface system	N/A	N/A
12	Lima - sustainable practices	Efficient Irrigation Systems	Functional Surface / Functional Element	Improved Irrigation	Efficient Irrigation Systems	N/A	N/A
13	Lima - sustainable practices	Energy Generation Systems as shading structures	Shading Unit	Shading measure / structure	Energy Generation Systems as shading structures	N	N
14	Lima - sustainable practices	Extensive or Intensive Green Roofs	Functional Surface / Functional Element	Vegetated Surface	Accessibility / Experimental (Green roof)	Y	N
15	Lima - sustainable practices	From water Treatment Plant within the plot	Functional Surface / Functional Element	Improved Irrigation	From water Treatment Plant within the plot	N/A	Y
16	Lima - sustainable practices	Garden Area	Functional Surface / Functional Element	Area / Space	Social Area	Y	N

APPENDIX 3 - CATEGORISATION OF LOCAL PRACTICES

Practice N°	City	Description	Practice Group	Practice Type	Practice	Vegetated	Water component
17	Lima - sustainable practices	Green Infrastructure	Functional Surface / Functional Element	Area / Space	Social Area	Y	N
18	Lima - sustainable practices	Green roof	Surface System	Vegetated surface	Green roof	Y	N
19	Lima - sustainable practices	Green roofs	Functional Surface / Functional Element	Vegetated Surface	Ornamental / Visible (Green roof)	Y	N
20	Lima - sustainable practices	Green wall	Surface System	Vegetated surface	Green wall	Y	N
21	Lima - sustainable practices	Intensive green roof, preferably with shrubs and trees	Surface System	Vegetated Surface	Green Roof Intensive (180 kg/m2), preferably with shrubs and trees	Y	N
22	Lima - sustainable practices	Intensive green roof	Surface System	Vegetated Surface	Green Roof Intensive (180 kg/m2), preferably with shrubs and trees	Y	N
23	Lima - sustainable practices	Landscaped Area	Surface System	Vegetated surface		Y	N
24	Lima - sustainable practices	Low water-using plants	Functional Surface / Functional Element	Vegetation	Drought-tolerance	Y	N
25	Lima - sustainable practices	Native plants / species	Functional Surface / Functional Element	Vegetation	Native or adapted plants	Y	N
26	Lima - other practices	Pastelero (terracotta)	Surface System	Impermeable surface	Pastelero (terracotta)	N	N
27	Lima - sustainable practices	Paver with high SRI values	Surface System	Reflective surface	Paver with high SRI values	N	N
28	Lima - sustainable practices	Pavers with 50% unbound	Surface System	Permeable surface	Pavers with 50% unbound	N	N
29	Lima - sustainable practices	Pedestrian-oriented pavers	Functional Surface / Functional Element	Area / Space	Accessibility / Experimental	N	N
30	Lima - sustainable practices	Permanent infiltration or collection features (e.g. vegetated swales)	Stormwater Management System	Detention, Retention and Infiltration system	Permanent infiltration or collection features (e.g. vegetated swales)	N/A	Y

APPENDIX 3 - CATEGORISATION OF LOCAL PRACTICES

Practice N°	City	Description	Practice Group	Practice Type	Practice	Vegetated	Water component
31	Lima - sustainable practices	Permeable Surfaces	Surface System	Permeable surface	Permeable surface	N	N
32	Lima - sustainable practices	Pipes	Stormwater Management System	Detention, Retention and Infiltration system	Pipes	N	Y
33	Lima - sustainable practices	Plant Species selection	Functional Surface / Functional Element	Vegetation	Plant Species selection	Y	N
34	Lima - sustainable practices	Rain garden	Stormwater Management System	Detention, Retention and Infiltration system	Rain garden	Y	Y
35	Lima - sustainable practices	Rainwater cistern	Stormwater Management System	Detention, Retention and Infiltration system	Rainwater cistern	N	Y
36	Lima - sustainable practices	Rainwater collection systems (tank)	Stormwater Management System	Detention, Retention and Infiltration system	Rainwater collection systems (tank)	N	Y
37	Lima - sustainable practices	Recreation oriented pavers	Functional Surface / Functional Element	Area / Space	Recreation Area	N	N
38	Lima - sustainable practices	Reflective Paint / Cool roof	Surface System	Reflective surface	Reflective Paint / Cool roof	N	N
39	Lima - sustainable practices	Roof (Solar reflectance min. 70%)	Surface System	Reflective surface	Roof (Solar reflectance min. 70%)	N	N
40	Lima - sustainable practices	Roof in open space	Shading Unit	Shading measure / structure	Shading Structure	N/A	N
41	Lima - other practices	Rubber	Surface System	Impermeable surface	Rubber	N	N
42	Lima - sustainable practices	Shading Architectural Structures or Devices	Shading Unit	Shading measure / structure	Shading Structure	N/A	N
43	Lima - sustainable practices	Shading Plants	Shading Unit	Shading measure / structure	Shading Plants	Y	N
44	Lima - sustainable practices	Technified irrigation systems	Functional Surface / Functional Element	Improved Irrigation	Improved Irrigation	N	Y
45	Lima - sustainable practices	Technified irrigation systems (drip irrigation or sprinklers)	Functional Surface / Functional Element	Improved Irrigation	Technified irrigation systems (drip irrigation or sprinklers)	N	Y

APPENDIX 3 - CATEGORISATION OF LOCAL PRACTICES

Practice N°	City	Description	Practice Group	Practice Type	Practice	Vegetated	Water component
46	Lima - sustainable practices	Tree planting	Shading Unit	Shading measure / structure	Shading Plants	Y	N
47	Lima - sustainable practices	Tree planting	Shading Unit	Shading measure / structure	Tree planting	Y	N
48	Lima - sustainable practices	Tree planting, principally at public space	Shading Unit	Shading measure / structure	Tree planting, principally at public space	Y	N
49	Lima - sustainable practices	Vaults	Stormwater Management System	Detention, Retention and Infiltration system	Vaults	N	Y
50	Lima - sustainable practices	Vegetated structures	Surface System	Vegetated surface		Y	N
51	Lima - sustainable practices	Wetlands	Surface System	Water body	Wetland	Y	Y
52	Lima - other practices	Wooden deck	Surface System	Impermeable surface	Wooden deck	N	N
53	Lima - sustainable practices	Xerophytic plants	Functional Surface / Functional Element	Vegetation	Drought-tolerance	Y	N

APPENDIX 4 - SUMMARY OF PRACTICES

		PREVIOUS GAR TOOLS	LIMA LOCAL GUIDELINES	LOCAL KNOWLEDGE
PRACTICE GROUP	**PRACTICE TYPE**	**PRACTICE**	**PRACTICE**	**PRACTICE**
Certification	**Building certification**		Building certification	
Hosting Unit	**Animal/Bug hosting structure**	Birdbox	Artificial Bee Hives	
		Branches		
		Bug feeder		
Shading Unit	**Shading measure / structure**	Shading Structure	Shading Structure	
			Energy Generation Systems as shading structures	
			Shading Plants	
			Tree planting	
			Tree planting, principally at public space	
Stormwater Management System	**Detention, Retention and Infiltration system**	Basin/Reservoir/Pond	Detention or retention ponds	
		Bioswale / Channel	Permanent infiltration or collection features (e.g. vegetated swales)	
		Drainage	Pipes	
		Green roof	Rain garden	
		Raingarden	Rainwater cistern	
		Detention, Retention and Infiltration system	Rainwater collection systems (tank)	
	Water harvesting system	Water harvesting system		
Surface System	**Eco-bridge / Faunal passage**	Eco-bridge / Faunal passage		
	Impermeable	Impermeable surface		Solar PV (as roof)
		Road / Path		Pastelero (terracotta)
		Roof surface		Artificial turf
		Waterproofing		Wooden deck
		Asphalt		
		Concrete		
	Permeable	(Block) With joints	Pavers with 50% unbound	Bare soil
		Block Grass	Permeable surface	
		Grassland		
		Lawn		
		Mulch		
		Permeable pavers		
		Gravel		
		Sand		
		High permeability		

	Rock	Native rock of Finland	
	Water body	Fountain Open water Pond Wetland Water body	Wetland
	Vegetated surface	Groundcovers	Green wall Green roof Intensive (180 kg/m2), preferably with shrubs and trees
	Reflective surface		Paver with high SRI values Reflective Paint / Cool roof Roof (Solar reflectance min. 70%)
Vegetation Unit	**Shrub**	Shrub	
	Tree	Canopy Large Canopy Medium Canopy Small Tree - Preserved	
Functional Surface	**Improved Irrigation**	From harvested water	Improved Irrigation Drip irrigation or under surface system Efficient Irrigation Systems From water Treatment Plant within the plot Technified irrigation systems (drip irrigation or sprinklers)
	Soil	Deep soil Open soil Shallow soil	
	Vegetation	Diversity of Vegetation Drought-tolerance Native Vegetation Ornamental / Visible Preserved Vegetation Strengthen Habitat	Drought-tolerance Native or adapted plants Plant Species selection
	Area / Space	Accessibility / Experimental Cultivation Social Technical Communal (Rooftop or Balcony) Communal (Terrace) Recreation	Accessibility / Experimental Public Space Area Recreation Area Social Area
	Vegetated surface	Visible (Green roof)	Ornamental / Visible (Green roof) Accessibility / Experimental (Green roof)

APPENDIX 5 – ENVIRONMENTAL PERFORMANCE ASSESSMENT CRITERIA

ASSESSED ECOSYSTEM SERVICES

- Flood risk reduction
- Thermal regulation
- Undisturbed nature
- Insect/Animal habitat
- Urban agriculture / Food provision
- Water saving
- Clean energy
- Aesthetic / Visual interest
- Social cohesion and recreation

ECOSYSTEM SERVICES NOT ASSESSED

- Noise Reduction
- Reduced Air Pollution
- Diversity

ASSESSED ECOSYSTEM SERVICES

Flood risk reduction	
Definition	The capacity of a practice to support on the retention, detention, infiltration and drainage of stormwater and river flooding
Criterion applied	Permeable surfaces allow rainwater to soak through the surface to be temporarily stored within the sub-base layer before soaking into the ground or flowing to the drains (Wilson et al., 2008). Some systems even include filtration mechanisms that allow rainwater to be treated before draining into water bodies. In previous GAFs, where 'Detention, Retention and Infiltration systems' and 'Permeable surfaces' were assigned high weightings (between 0.80 to 0.90 out of 1) and 'Impermeable Surfaces' with the lowest weighting (0). Some cities even included a 'Stormwater Management' section with a set of different permeable surfaces, including NBSs such as raingardens and bioswales (e.g. Practice N° 209). Similar practices were observed in the international certifications used in Lima. However, current regulations incentivise the uptake of NBSs - particularly based on indigenous knowledge - as a matter of contributing to water security and the optimal development of local agriculture (Ochoa-Tocachi et al., 2019). Local scant rainfall in arid cities may make this attribute less interesting for the urban scope. However, changed rainfall patterns, river flows and sea level rise are expected for coastal cities (The Arab Water Council, 2009). In Lima, variations due to climate change and unpredictable El Niño events may intensify these issues (PROACC, 2018; Siña, 2016). Hence, keeping the permeability of soil is a condition of high importance as it significantly

	contributes to develop resilience against unexpected climate events. Based on these approaches, the metric proposed by Keeley (2011) with respect to 'Water Infiltration Storage' was used as guidance.
Result	Based on Keeley´s approach (2011), 'Permeable surfaces', 'Tree', 'Shrubs' and 'Connected soils' received the highest score (3 points), followed by 'Semi-permeable surfaces', which received 2 points. The lowest score was attributed to 'Green Walls' and all 'Impermeable surface', 'Water features' and 'Shading measures', as well as, to 'Unconnected soils'.

Thermal regulation	
Definition	The capacity of a practice to perform as an Urban Heat Island (UHI) mitigation strategy by either cooling or producing a minimal warming effect in air temperature (AT) over the area where they implemented.
Criterion applied	A number of scenarios were tested in a microclimate analysis using ENVI-met. Higher points were assigned to practices that either cooled or had a minimal warming effect over the area, that is they maintained or decreased the air temperature in comparison to the atmosphere temperature values used as input in the software.
Result	Refer section 5.

Undisturbed nature	
Definition	The capacity of a practice to encourage the preservation of existing trees.
Criterion applied	The label of 'undisturbed nature' encompasses for this assessment the avoidance of disturbance to which existing and local vegetation is prone due to construction and gardening practices. It encompasses the preservation of existing trees and shrubs and the promotion of use of native (non-invasive) or well-adapted species, as a matter to avoid disturbances in the natural cycle already established in the local ecosystem. For instance, due to the long lifespan of trees, these are very likely to be disturbed by at least one construction practice (e.g. new buildings, sidewalks, etc), which limits its expected life rate (Hauer et al., 2020). These two principles of action were identified in practices suggested by previous GAFs. However, the approach of local guidelines considered fostering only the use of native species, with no metric or detailed guidance established. In comparison to other cities - limited local public and official information that guide on this respect was found through the Literature Review. Information on which species are well-adapted and native of Lima was found only in one official public source (See MML, 2013). In the case of preservation practices the age and size of the specie (e.g. Practices N° 3, 98, 188) and the inclusion of ‘Enhanced-tree-growth systems’ (Practice N° 197) was used as a metric of effectiveness in their tools. While this approach may be sufficient, as in general younger trees can withstand disturbances better than larger, mature trees (The Morton Arboretum, 2020), many other conditions, such as specie (The Morton Arboretum, 2020; Hauer et al., 2020) can determine its survival, growth, health and condition after disturbances.
Result	Establishing to what extent a practice can protect or disturb existing vegetation through its physical attributes (surfaces) in these senses may demand profound research and it is out of the scope of this work. Notwithstanding, avoiding disturbances can be considered, as a starting

	point, as a 'Functional Surface'. Therefore, the use of native species is not assessed, but it was rather established as a suggestion of high consideration. On the other hand, 3 points were given to the practice 'Vegetation - Trees – Preserved' to boost the weighting of a 'Vegetation Unit' that includes this consideration in the project.

Insect/Animal habitat	
Definition	The capacity of a practice to host animal and insect habitat (biotopes).
Criterion applied	Habitats and biotopes are areas in which certain plants and animals form a community (Hemeier, 2005). In urban areas, they are important because they provide functions such as species protection, recreation, cultural development, well-being, and environmental health (Sukopp and Weiler, 1988). Moreover, human interference and interaction are usually necessary for the protection and regeneration of a biotope, but in natural habitats, human interaction normally has detrimental effects (Chepkemoi, 2017). While both terms are sometimes used interchangeably, biotopes have a microscale nature and is based on a biological community, while a habitat is not limited to a specified geographical area and can cover a large or a microscopic area (Chepkemoi, 2017). Therefore, implementing elements in the landscape that determine the successful creation of these environment is very complex and would demand profound research and assessment. However, at a high level, it is highly likely that natural elements develop more supporting conditions to host diverse species in comparison to non-natural elements, as long as they are inserted in the landscape under conditions that limit disturbances and risks. This approach was observed in the analysis of the BAF developed by Keeley (2011), where it was established vegetated surfaces (including green walls and roofs) contributed highly to the development of habitats and biotopes in comparison with semipermeable and impermeable (low) or shallow soils (moderate). This means areas with connection to soil have greater capacity to provide habitat than those with shallow soil (e.g. extensive green roofs). This approach was found sufficient for the scope of this research.
Result	All practices based on vegetation that are likely to be in deep or connected soil received 3 points as well as 'Wetland'. Two points were granted to 'Surfaces' that are composed of natural materials (including water in the case of 'Fountain') and support vegetation. One point was given to 'Semipermeable' surfaces that included vegetation partially. All 'Impermeable Surfaces' and those not supporting vegetation received the lowest score (0 points). Vegetation growth can be limited by the soil depth. Therefore, additional scores were given in 'Soil Connection' to boost practices' weightings according to the soil condition they considered. Consequently, 'Connected to soil' received the highest score (3 points) and deep and shallow soils 2 and 1 points, respectively. Finally, previous analyses suggested the inclusion of habitat units (e.g. animal shelters) within the landscaping projects. Therefore, 3 points were added to projects that present this consideration.

Urban agriculture / Food provision	
Definition	The capacity of a practice to host agriculture activities at an urban scale.
Criterion applied	Agriculture encompasses food production from vegetation and animals. Locally grown food is important to reduce transportation and create more sustainable urban areas (Delshammar, p. 9, 22 cited in Spjuth, 2016). While this expectation could be covered if agriculture takes a sufficient scale in quantity to satisfy a community, incorporating this practice within limited urban green spaces as roofs or balconies can bring also positive outcomes, for instance, it can contributes to the reuse of water and urban waste (World Bank, 2013) apart from increasing green areas. Fostering urban agriculture at a microscale can deliver knowledge and build capacity in the topic over time, which can increase its adequate applicability in the near future. While the spatial arrangement, including the microclimate, solar and wind exposure, and irrigation are factors that determine the effectiveness of results, at least of productive vegetation, there is a significant amount of species that have proved to reproduce successfully within limited urban spaces, with minimal demanding requirements.
Result	Areas intended for the development of this practice received 3 points, as they have considered the adequate spatial requirements for this activity to take place. A specific 'intended use' was included to this end.

Water saving	
Definition	The capacity of a practice to guarantee limited water resources are needed and reduce dependency on potable water.
Criterion applied	Maintaining urban green spaces is resource-intensive (Nouri et al., 2019), particularly when using potable water. Utilising native desert landscaping can reduce strain on water resources (Yang and Wang, 2017). Native plant species of arid environments can be maintained with very little water or even without irrigation at all (Nouri et al., 2019). Drought-tolerant plants or xerophytes, for instance succulents or cactus, are highly resistant to these conditions (Brescia de Fort et al., 2010) in comparison to lawns (Arup, 2018). But water saving should not be limited solely to species selection but also include their patterns of water use (Nouri et al., 2019). Efficient irrigation systems (e.g. drip irrigation, sprinklers, underground irrigation) reduce consumption by distributing the necessary quantity of water according to plants' needs (e.g. whether it needs it principally on the root or leaves). In some cases, accompanied by 'smart controls' they help automatize irrigation schedule and measure the quantity of use, reducing demanding tasks on maintenance and potential system failures. A way to reduce consumption of potable water is to treat and use grey water coming from domestic activities such as cooking and showering. While a more energy and space intensive approach, water treatment plants – based on chemical or nature-based solutions (NBSs), as artificial wetlands – have proved to deliver a sufficient level of decontamination as to ensure good health conditions of both vegetation and humans. NBSs are also socially accepted in desert cities (Hagen et al., 2017) and undesirable odour can be mitigated with appropriate design (Eisenberg et al., 2014).
Result	Areas using drought tolerant vegetation and using minimal vegetation received 3 points. For other types of vegetation, if high efficiency irrigation with treated water is used, it received 2 points, while standard irrigation with

	recycled water received 1 point. Any irrigation method using potable water received zero points. ‘Surface systems’ and 'Shading structures' without vegetation which do not require water for maintenance were assigned 3 points. ‘Groundcover’, ‘Green wall’, ‘Combined green/grey surface’, ‘Tree’ and ‘Shrub’ were given 1 point, while ‘'Lawn’ was given 0 points, as it typically is water intensive. ‘Wetland’ was given 3 points as it facilitates water storage and treatment. ‘Fountain’ received 0 points as they often require replenishment due to evaporations.

Clean energy	
Definition	The capacity of a practice to generate clean energy during its lifetime
Criterion applied	The majority of Peru's electricity generation comes from renewable sources - 59.4% in 2017 - with 54.9% sourced from hydroelectricity. However, the remainder is sourced from fossil fuel combustion - primarily natural gas (IEA, 2020). Further, climate change may reduce the potential for power generation from hydropower (World Bank, 2007a). Solar photovoltaic (PV) has become a mature technology which could assist countries like Peru reduce reliance on electricity sourced from fossil fuels and therefore reduce greenhouse gas and other air pollutant emissions. However, in Lima, in the absence of financial support for the implementation of small-scale solar PV systems, it is unlikely such a system will be profitable - due to the reduced energy yield as clouds reduce solar irradiation, and increased costs of maintenance due to cleaning of dust (Espinoza et al., 2019).
Result	3 points were given to surfaces that include solar panels on roof surfaces or on shading structures.

Aesthetic / Visual interest	
Definition	The capacity of a practice to contribute to the increase of the attractiveness of the urban environment, through the increase of the quantity of natural ornamental elements in the landscape, while delivering positive emotions and sensorial experiences.
Criterion applied	While measuring aesthetics could be highly subjective and may depend on many local factors, for the purpose of this study, a human-innate approach was considered sufficient. Water, flowers and trees are considered special attractions in cities (Gehl, 2010). This fact can be better understood under the Biophilia hypothesis. It states humans have an innate and inherent affinity and appreciation for nature, due to their positive impact in mental health and wellbeing. Based on this hypothesis, Kellert and Calabrese (2015) developed a classification framework that categorises landscape elements depending on how direct (or indirect) they deliver ‘experience with nature'. This means that the more natural the visible elements of composition of a practice are, the more direct the experience with nature will be delivered, and therefore, the more likely the elements to be appealing. On the other hand, the authors also introduced the idea of 'weather' and argue that if the element can bring a sense of refuge it may also bring a positive outcome.

Direct experience of nature	Indirect experience of nature	Experience of space and place
• Light • Air • Water • Plants • Animals • Weather • Natural landscapes and ecosystems	• Images of nature • Natural materials • Natural colours • Simulating natural light and air • Naturalistic shapes and forms • Evoking nature	• Prospect and refuge • Organised complexity • Integration of parts to wholes • Transitional spaces • Mobility and wayfinding • Cultural and ecological attachment to place

Result

Based on the classification framework developed by Kellert and Calabrese (2015) only physical attributes were considered (i.e. no Functional Surfaces). The highest scores were given to vegetated surfaces and water as they provide direct experience with nature (3 points). Practices with minimal vegetation, made of natural materials, ornamental features or mimicking (evoking) nature such as artificial turf and water features received 2 points. Shading structures deliver comfort and protection from extreme warm temperatures. Therefore, all were granted with 1 point, but the one with vegetation received 3 additional. Other practices may also have aesthetic values, but this may be subjected to the preference in the design, hence they received 0 points.

Social cohesion and recreation

Definition

The capacity of a practice to host social and facilitate leisure activities (individual or collective) with amenities for human interaction

Criterion applied

Within natural landscapes, the recreational values can depend on ecological characteristics but also on built infrastructure such as availability of benches and sport facilities (Gómez-Baggethun et al., 2013). Green spaces particularly amplify recreational activities (Vogt et al., 2017). Offering public amenities that invite to remain or facilitate sharing common interests within the same space increases city´s life. Gehl (2010; 2006), for instance, indicates inviting spaces are necessary to effectively deliver liveability and lengthy stays in public areas is an indicator of this. If there is life and activity, social exchange is likely to happen, which stimulates entertainment and strengthen social relations (social cohesion). A practice that has demonstrated effective results in this regard is for instance urban agriculture (World Bank, 2013; Azunre et al., 2019).

The social environment plays an important role in people´s health and well-being (Jennings and Bamkole, 2019). However, access to greenery has also proved to bring positive outcomes in this respect (James et al., 2016) to the extent it can influence behavioural change and contribute positively to individual and collective resilience (Beatley, 2016). Apart from stimulating the experience of the built environment, access to green space is a matter of environmental justice (Jönsson, 2016). Therefore, the more a practice facilitates, attracts and invites to remain in the place, allows to share and use amenities within the space, the higher the score will be.

Result	Weightings were given only to practices within the 'Functional Surface' section. This means that these attributes can be incorporated as a layer over surfaces. The highest score (3 points) was given to practices that promote either recreation or social activities or urban agriculture within a surface at the time. Inaccessible vegetated areas that are exclusively ornamental, or solely to look at, received only 1 point, as they contribute to access to nature but with significant visitor limitations. Additionally, 3 points were assigned to 'Donation of private area or shade for public use (donated surface area + tree canopy area in public space)' as it facilitates social activities within its space.

ECOSYSTEM SERVICES NOT ASSESSED

Noise Reduction	
Definition	The capacity of a practice to reduce noise.
Criterion applied	Natural (e.g. animal vocalizations, wind, thunders) and environmental events and activities (Han et al., 2018) can be sources of noise within urban areas. However, in the urban scope especial attention is given to the reduction of disturbances from road traffic. Noise barriers encompass walls, earthen berms (or in combination) (Kalansuriya et al., 2009) made of different materials (surfaces) such as wood, concrete, masonry, and metal (Kotzen and English, 2009 cited in Halim et al., 2015), including vegetation as trees and shrubs belts (Peng at al., 2014). Notwithstanding, they are highly subjected to intrinsic variables such as thicknesses (Halim et al., 2015). This include vegetated barriers, which have great potential to perform as natural buffers (Koprowska et al., 2018). However, the density of leaves, as well as external variables such as meteorological and spatial conditions (Gallagher et al., 2015), including materials from surrounding buildings can also highly influence their effectiveness (Kalansuriya et al., 2009; Vladimir and Madalima, 2019).
Result	Given the limited information about its relevance in Lima, in addition to the site-specific requirements for practices to be effective, no practice was assessed against this ES.

Reduced Air Pollution	
Definition	The capacity of a practice to reduce air pollution.
Criterion applied	Due to the high levels of particle matter (PM) present in local air (average of 28.0 µg/m3 of PM 2.5 (IQ Air, 2018)), the reduction through dispersion and deposition - favoured principally by vegetation - from a collective approach (at pedestrian areas) was assumed. However, literature revealed this approach demands the consideration of several conditions which made the criterion assessment highly complex. Studies indicated vegetation species (Sæbø et al.2012; Wang et al., 2019), leaf area density (Beckett et al., 2000), canopy size (Nowak et al., 2006; McDonald et al., 2007), growing season (Nowak et al. 2006; Muñoz et al., 2017), spatial arrangement of units: individual or grouping (McDonald et al., 2007; Abhijith et al., 2017; Wang et al., 2019; Abhijith and Kumar, 2019), climatic conditions (e.g. wind direction) (Gallagher et al., 2015) and interaction with species location and pollutant source within the urban canyon (Yang et al., 2008; Speak et al., 2012;

	Taleghani et al., 2020) influence highly in the effective performance of vegetation as a reduction measure. Not considering these factors had resulted detrimental in the case of some practices, for instance in tree-planting, since some street scenarios have prevented the dispersion and ventilation of pollutants (Vos et al., 2013; Abhijith and Kumar, 2019).
Result	Given the high number or variables and potential for detrimental effects if not considered, no practice was assessed against this ES.

Diversity	
Definition	The capacity of a practice to increase biodiversity.
Criterion applied	Monoculture have proved to have counterproductive outcomes for ecosystems (Gioannini et al., 2018). However, planting a wide variety of species for the sole purpose of diversification can also be counterproductive if they are not well-adapted to local conditions (McPherson and Kotow, 2013) they can lead to a great loss of biodiversity (Swearingen and Bargeron, 2016).
Result	Given the limited information and its low relevance for Lima, no further assumptions were executed. Hence, it was determined not to assess any practice against this ES

APPENDIX 6 - ENVI-MET SCENARIOS

	Roof		Wall		Street		Vegetation Units				Surface greening				
Scenario ID	**Surface System**	**Representative material in ENVI-met**	**Surface System**	**Representative material in ENVI-met**	**Surface System**	**Representative material in ENVI-met**	**Surface System**	**Representative vegetation in ENVI-met**	**Height / Crown (m)**	**Application**	**Surface System**	**Representative vegetation in ENVI-met**	**Soil depth (m)**	**Plant Height (m)**	**Application**
Base Case	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt	0100ST Asphalt road									
S1	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Bare soil	LOA100 Loamy Soil									
S2	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Sand	0100SD Sand									
S3	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Concrete (Impermeable paver)	0100PP Pavement Concrete, used/dirty									
S4	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Wooden deck	0100WD Wood Planks									
S5	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Lawn	0100XX Grass 25 cm aver. dense									
S6	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Groundcovers	010000 Funkia (Hosta)									
S7	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Combined green/grey (Permeable paver)	Grid pattern: 50% 0100PP Pavement Concrete, used/dirty; 50% 0100XX Grass 25 cm aver. dense									
S8	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Fountain	0100WW Deep Water									
S9	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Wetland	0100WW Deep Water					Lawn	0100XX Grass 25 cm aver. dense	N/A	0.25	Street
S10	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Red terracotta tile	0101LR Loamy soil + red terracotta tile									
S11	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt - Light (SRI 100)	WHASPH Asphalt road, white									
S12	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Concrete - Light (SRI 100)	0100PL Concrete Pavement Light									

APPENDIX 6 - ENVI-MET SCENARIOS

Scenario ID	Roof		Wall		Street		Vegetation Units				Surface greening				
	Surface System	**Representative material in ENVI-met**	**Surface System**	**Representative material in ENVI-met**	**Surface System**	**Representative material in ENVI-met**	**Surface System**	**Representative vegetation in ENVI-met**	**Height / Crown (m)**	**Application**	**Surface System**	**Representative vegetation in ENVI-met**	**Soil depth (m)**	**Plant Height (m)**	**Application**
GW1	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt	0100ST Asphalt road					Green Wall	01NADS Green + mixed substrate	0.15	0.3	Wall
R1	Concrete	0100C5 Concrete cast dense	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt	0100ST Asphalt road									
GR1	Concrete + Roof greening	0100C5 Concrete cast dense	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt	0100ST Asphalt road					Extensive green roof - Ground cover on shallow soil	GRBRE1 - 10cm greening (Funkia (Hosta)) on 20cm substrate	0.2	0.1	Roof
GR2	Concrete + Roof greening	0100C5 Concrete cast dense	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt	0100ST Asphalt road					Intensive green roof - Lawn on deep soil	GRBRE3 - 7cm greening (grass) on 1m substrate	1	0.7	Roof
GR3	Concrete + Roof greening	0100C5 Concrete cast dense	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt	0100ST Asphalt road					Intensive green roof - Shrubs on deep soil	GRBRE4 - 60cm greening (hedge dense) on 1m substrate	1	0.6	Roof
GR4	Concrete + Roof greening	0100C5 Concrete cast dense	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt	0100ST Asphalt road	Tree	01SLDS - Tree - Spherical, large trunk, dense, small (5m)	5 / 3	Roof	Intensive green roof - Shrubs and trees on deep soil	GRBRE4 - 60cm greening (hedge dense) on 1m substrate	1	0.6	Roof
GR5	Concrete + Roof greening	0100C5 Concrete cast dense	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt	0100ST Asphalt road					Green roof - Wetland	GRBRE6 - 60cm grass on 20cm water and 40cm total substrate	0.4	0.6	Roof
VU1	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt	0100ST Asphalt road	Tree	(01SLDM) Spherical Large Trunk dense medium 15m)	15 / 11	Street					
VU2	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Concrete	0100PP Pavement Concrete, used/dirty	Tree	(01SLDM) Spherical Large Trunk dense medium 15m)	15 / 11	Street					
VU3	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Bare soil	LOA100 Loamy Soil	Tree	(01SLDM) Spherical Large Trunk dense medium 15m)	15 / 11	Street					
VU4	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Lawn	0100XX Grass 25 cm aver. dense	Tree	(01SLDM) Spherical Large Trunk dense medium 15m)	15 / 11	Street					

APPENDIX 6 - ENVI-MET SCENARIOS

	Roof		Wall		Street		Vegetation Units				Surface greening				
Scenario ID	**Surface System**	**Representative material in ENVI-met**	**Surface System**	**Representative material in ENVI-met**	**Surface System**	**Representative material in ENVI-met**	**Surface System**	**Representative vegetation in ENVI-met**	**Height / Crown (m)**	**Application**	**Surface System**	**Representative vegetation in ENVI-met**	**Soil depth (m)**	**Plant Height (m)**	**Application**
VU5	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Asphalt	0100ST Asphalt road	Shrub	(0100H4) Hedge dense, 4m	4 / N/A	Street					
VU6	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Concrete	0100PP Pavement Concrete, used/dirty	Shrub	(0100H4) Hedge dense, 4m	4 / N/A	Street					
VU7	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Bare soil	LOA100 Loamy Soil	Shrub	(0100H4) Hedge dense, 4m	4 / N/A	Street					
VU8	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Lawn	0100XX Grass 25 cm aver. dense	Shrub	(0100H4) Hedge dense, 4m	4 / N/A	Street					
EGR 1	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Extensive green roof	GREX01 Green roof extensive as soil					Lawn	0100XX Grass 25 cm aver. dense	0.2	0.25	Street
IGR1	Red terracotta tile	TLRED1 Terracotta (Pastelero)	Concrete	0100C3 Concrete Wall - Hollow block	Intensive green roof	GRIN01 Green roof intensive as soil					Lawn	0100XX Grass 25 cm aver. dense	1	0.25	Street

APPENDIX 7 - ENVI-MET MATERIALS

Surfaces

Surface code	Surface description	Surface type	Composition										
			Layer 1 material	Layer 1 thickness (m)	Layer 2 material	Layer 2 thickness (m)	Layer 3 material	Layer 3 thickness (m)	Total thickness (m)	Roughness length	Albedo	Emissivity	SRI
TLRED1	Terracotta (Pastelero)	Wall / Roof	0100R2 Roofing: Terracotta	0.02	0100O2 Air	0.02	01000C5 Concrete cast dense	0.26	0.30	0.02			
TLRED2	Terracotta (Pastelero) painted white	Wall / Roof	0100R3 Roofing: Terracotta painted white	0.02	0100O2 Air	0.02	01000C5 Concrete cast dense	0.26	0.30	0.02			
0100C3	Concrete Wall - Hollow block	Wall / Roof	0000C3 Concrete: hollow block	0.10	0000C3 Concrete: hollow block	0.10	0000C3 Concrete: hollow block	0.10	0.30	0.02			
0100C5	Concrete cast dense	Wall / Roof	0000C5 Concrete: cast dense	0.10	0000C5 Concrete: cast dense	0.10	0000C5 Concrete: cast dense	0.10	0.30	0.02			
0100R2	Roofing: Terracotta	Wall / Roof	0000R2 Roofing: Terracotta	0.10	0000R2 Roofing: Terracotta	0.10	0000R2 Roofing: Terracotta	0.10	0.30	0.02			
0100ST	Asphalt road	Surface profile	0000AB Asphalt (with Basalt)	0.30	0000SL Sandy loam	4.20	N/A		4.50	0.01	0.20	0.90	19
0100LO	Loamy Soil	Surface profile	0000SL Sandy loam	4.50	N/A		N/A		4.50	0.02	0.00	0.98	-2
0100SD	Sandy soil	Surface profile	0000SD Sand	0.06	0000SL Sandy loam	4.44	N/A		4.50	0.05	0.00	0.90	-6
0100PP	Pavement (Concrete), used/dirty	Surface profile	0000ZB Cement concrete	0.04	0000SD Sand	0.02	0000SL Sandy loam	4.44	4.50	0.01	0.30	0.90	32
0100WD	Wood Planks	Surface profile	0000WD Wood Planks	0.10	0000SD Sand 0000LS Loamy sand	0.20	0000SL Sandy loam	4.20	4.50	0.01	0.80	0.90	100
WHASPH	Asphalt road, white	Surface profile	0000AB Asphalt (with Basalt)	0.30	0000SL Sandy loam	4.20	N/A		4.50	0.01	0.80	0.90	100
0101LR	Loamy soil + red terracotta tile	Surface profile	SOITER Terracotta (soil)	0.02	SOIAIR Air (Soil) 0000ZB Cement concrete	0.02 0.26	0000SL Sandy loam	4.20	4.50	0.02	0.50	0.90	58
0102LR	Loamy soil + red terracotta tile (no air)	Surface profile	SOITER Terracotta (soil)	0.04	0000ZB Cement concrete	0.26	0000SL Sandy loam	4.20	4.50	0.02	0.50	0.90	58

Surfaces (cont)			Composition										
Surface code	**Surface description**	**Surface type**	**Layer 1 material**	**Layer 1 thickness (m)**	**Layer 2 material**	**Layer 2 thickness (m)**	**Layer 3 material**	**Layer 3 thickness (m)**	**Total thickness (m)**	**Roughness length**	**Albedo**	**Emissivity**	**SRI**
0100WW	Deep Water	Surface profile	0000WW Water	4.50	N/A		N/A		4.50	0.01	0.00	0.96	-3
CONWH1	Concrete pavement light	Surface profile	0000ZB Cement concrete	0.04	0000SD Sand	0.02	0000SL Sandy loam	4.44	4.50	0.01	0.80	0.90	100
0100PL	Concrete Pavement Light	Surface profile	0000ZB Cement concrete	0.04	0000SD Sand	0.02	0000SL Sandy loam	4.44	4.50	0.01	0.80	0.90	100
GREX01	Green roof extensive as soil	Surface profile	0000SL Sandy loam	0.10	0000BS Smashed brick 0000ZB Cement concrete	0.10 0.30	0000SL Sandy loam	4.00	4.50	0.015	0.00	0.98	-2
GRIN01	Green roof intensive as soil	Surface profile	0000SL Sandy loam	1.00	0000ZB Cement concrete	0.50	0000SL Sandy loam	3.00	4.50	0.015	0.00	0.98	-2

Surface greening			Plant		Substrate										
Greening code	**Greening description**	**Type**	**Plant type**	**Plant thickness (m)**	**Layer 1 material**	**Layer 1 thickness (m)**	**Layer 2 material**	**Layer 2 thickness (m)**	**Layer 3 material**	**Layer 3 thickness (m)**	**Total substrate thickness (m)**	**Emissivity**	**Albedo**	**Water coefficient**	**Air gap between substrate and wall (m)**
01NADS	Green + mixed substrate	Surface greening	0100FU Funkia Hosta	0.30	0000SL Sandy loam	0.05	0000SL Sandy loam	0.05	0000SY Styrofoam	0.05	0.15	0.95	0.3	0.5	0.01
GRBRE1	10cm greening (Funkia (Hosta)) on 20cm substrate	Surface greening	0100FU Funkia Hosta	0.10	0000LE Loam	0.10	0000BS Smashed brick	0.09	0000AB Asphalt (with Basalt)	0.01	0.20	0.95	0.3	0.5	0.01
GRBRE3	7cm greening (grass) on 1m substrate	Surface greening	0100XX Grass 25 cm aver. Dense	0.07	0000LE Loam	0.80	0000BS Smashed brick	0.19	0000AB Asphalt (with Basalt)	0.01	1.00	0.95	0.3	0.5	0.01
GRBRE4	60cm greening (hedge dense) on 1m substrate	Surface greening	0100H4 Hedge dense, 4m	0.60	0000LE Loam	0.80	0000BS Smashed brick	0.19	0000AB Asphalt (with Basalt)	0.01	1.00	0.95	0.3	0.5	0.01
GRBRE6	60cm grass on 20cm water and 40cm total substrate	Surface greening	0100XY	Grass 50 cm aver. Dense	0000WW Water	0.20	0000BS Smashed brick	0.17	0000AB Asphalt (with Basalt)	0.03	0.40	0.95	0.3	0.5	0.01

Materials

Material code	Material description	Type	Absorption (Frac)	Transmission (Frac)	Reflection (Frac)	Emissivity (Frac)	Specific Heat (J/(Kg*K))	Thermal conductivity (W/(m*K))	Density (kg/m3)
0000C3	Concrete: hollow block	Material	0.70	0.00	0.30	0.90	840.00	0.86	930.00
0000C5	Concrete: cast dense	Material	0.70	0.00	0.30	0.90	840.00	1.90	2500.00
0000R2	Roofing: Terracotta	Material	0.50	0.00	0.50	0.90	840.00	0.81	1700.00
0100O2	Air	Material	0.00	1.00	0.00	0.96	1006.00	0.03	1.20

Soils

Soil code	Soil description	Type	Water content at saturation (m3/m3)	Water content at field capacity (m3/m3)	Water capacity at wilting point (m3/m3)	Matrix potential (m3)	Hydraulic conductivity (m/s*10^-6)	Volumetric heat capacity (J/(m3K)*10^-6)	Clapp & Hornberger Constant	Heat conductivity (W/mK)	Other information
SOIAIR	Air (Soil)	Artificial material	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.025	Custom created soil to replicate terracotta tile and green roofs on ground
SOITER	Terracotta (soil)	Artificial material	0.000	0.000	0.000	0.000	0.000	2.000	0.000	0.810	Custom created soil to replicate terracotta tile on ground
0000ZB	Cement concrete	Artificial material	0.000	0.000	0.000	0.000	0.000	2.083	0.000	1.630	
0000SD	Sand	Natural soil	0.395	0.135	0.007	-0.121	176.000	1.463	4.050	0.000	
0000LS	Loamy sand	Natural soil	0.410	0.150	0.075	0.090	16.300	1.404	4.380	0.000	
0000SL	Sandy loam	Natural soil	0.435	0.195	0.114	-0.218	34.100	1.320	4.900	0.000	
0000AB	Asphalt (with Basalt)	Artificial material	0.00	0.00	0.00	0.00	0.00	2.25	0.00	0.90	
0000WD	Wood Planks	Artificial material	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.90	
0000WW	Water	Water body (deep)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
0000BS	Smashed brick	Natural soil	0.40	0.14	0.01	-0.12	176.00	2.00	4.05	0.00	
0000SY	Styrofoam	Artificial material	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.10	

Vegetation units

Vegetation code	Vegetation description	Vegetation type	Leaf type	Albedo	Transmittance	Plant height (m)	Plant width (m)	Root zone depth (m)	Diameter of roots (m)
0100XX	Grass 25 cm aver. dense	2D Plant	Gras	0.20	0.30	0.50	N/A	0.50	N/A
010000	Funkia (Hosta)	2D Plant	Deciduous	0.20	0.30	0.40	N/A	0.50	N/A
0100H4	Hedge dense, 4m	2D Plant	Deciduous	0.20	0.30	4.00	N/A	1.00	N/A
01SLDS	Tree - Spherical, large trunk, dense, small (5m)	3D Plant	Deciduous	0.18	0.30	5.00	3.00	3.00	3.00
01SLDM	Spherical Large Trunk dense medium 15m)	3D Plant	Deciduous	0.18	0.30	15.00	11.00	12.00	9.00

APPENDIX 8 - ENVI-MET SCENARIO MATRIX

		Scenarios compared to assess the effect of…					
Scenario ID	**Scenario**	**System Surfaces at street level**	**Green Wall at street level**	**Different roof systems**	**Adding Vegetation Units (trees, shrubs) to Surface Systems**	**Soil connectivity**	**Surface reflectivity**
Base Case	Asphalt street + Red terracotta roof	✓	✓	✓	✓		✓
S1	Bare soil street + Red terracotta roof	✓			✓		
S2	Sand street + Red terracotta roof	✓					
S3	Concrete street + Red terracotta roof (Impermeable paver)	✓			✓		✓
S4	Wooden deck street + Red terracotta roof	✓					
S5	Lawn street + Red terracotta roof	✓			✓	✓	
S6	Groundcovers street + Red terracotta roof	✓					
S7	Combined green/grey street + Red terracotta roof (Permeable paver)	✓					
S8	Fountain street + Red terracotta roof	✓					
S9	Wetland street + Red terracotta roof	✓					
S10	Red terracotta tile street + Red terracotta roof	✓					
S11	Asphalt - Light (SRI 100) street + Red terracotta roof						✓
S12	Concrete - Light (SRI 100) street + Red terracotta roof						✓
GW1	Base Case + Green wall		✓				
R1	Concrete roof (Asphalt street)			✓			
GR1	Extensive green roof - Ground cover on shallow soil (Asphalt street)			✓			
GR2	Intensive green roof - Lawn on deep soil (Asphalt street)			✓			
GR3	Intensive green roof - Shrubs on deep soil (Asphalt street)			✓			
GR4	Intensive green roof - Shrubs and trees on deep soil (Asphalt street)			✓			
GR5	Green roof - Wetland (Asphalt street)			✓			
EGR1	Lawn on shallow soil (extensive) on street + Red terracotta roof					✓	
IGR1	Lawn on deep soil (intensive) on street + Red terracotta roof					✓	
VU1	Asphalt street + Tree				✓		
VU2	Concrete street + Tree				✓		
VU3	Bare soil street + Tree				✓		
VU4	Lawn street + Tree				✓		
VU5	Asphalt street + Shrub				✓		
VU6	Concrete street + Shrub				✓		
VU7	Bare soil street + Shrub				✓		
VU8	Lawn street + Shrub				✓		

APPENDIX 9 - APPLICATION OF THE TOOL

		Project					
		Olavide		Huaylas		Palas	
Practice	Weighting	Area (m^2)	GAR-Score	Area (m^2)	GAR-Score	Area (m^2)	GAR-Score
Surface System							
Concrete	**0.33**	182.07	0.17	2,992.10	0.20	1,956.53	0.25
Gravel	**0.63**	-	-	-	-	41.95	0.01
Groundcovers	**0.67**	-	-	-	-	60.95	0.02
Lawn	**0.56**	177.43	0.28	1,880.80	0.22	265.66	0.06
Solar PV	**0.56**	-	-	-	-	244.80	0.05
Wooden deck	**0.52**	-	-	8.60	0.00	4.50	0.00
Vegetation Unit							
Tree	**0.78**	-	-	30.00	0.00	80.00	0.02
Shading Unit							
Shading structure	**0.48**	-	-	-	-	57.48	0.01
Functional Surface							
Area intended for recreation in donated public/semi-private spaces (e.g. playground, sports areas within donated public spaces or multifamilar shared spaces, etc.)	**0.33**	-	-	-	-	111.35	0.01
Area intended for social interaction in donated public/semi-private spaces (e.g. social areas with furniture within multifamiliar development, social shared spaces within the same development, etc.)	**0.33**	-	-	8.60	0.00	72.67	0.01
Non-accessible vegetated area, visible from public pedestrian area (not intended for activity (e.g. ornamental garden)	**0.11**	22.82	0.01	157.40	0.00	48.61	0.00
Connected soil	**0.22**	-	-	1,416.70	0.06	234.41	0.02
Unconnected - Deep soil (incl. Intensive green roof)	**0.07**	-	-	464.10	0.01	-	-
Unconnected - Shallow soil (incl. Extensive green roof)	**0.04**	177.43	0.02	-	-	134.15	0.00
Vegetation - standard irrigation with potable water	**0.00**	177.43	-	1,910.80	-	345.66	-
Sum (Practice areas * weightings)		169.05		2,432.83		1,214.12	
Plot area (excl Green Wall)		359.50		4,881.50		2,574.39	
GAR-Score		**0.47**		**0.50**		**0.47**	

APPENDIX 10 - APPLICATION OF THE TOOL - OLAVIDE PROJECT

			Water sensitive scenarios							
		BC	**X1**	**G1**	**X2**	**X3**	**X4**	**G2**	**G3**	**X5**
		Base case	**Xeriscape intensive (drought tolerant groundcover + trees)**	**Lawn intensive (BC) + high efficiency irrigation using treated grey water + wetland (wtp) + trees**	**Xericape intensive (bare soil + trees drought tolerant)**	**Xeriscape extensive (drought tolerant groundcover)**	**Xeriscape intensive (gravel + drought tolerant trees)**	**Lawn extensive (BC) + high efficiency irrigation using treated grey water + wetland (wtp)**	**Lawn extensive (BC) + high efficiency irrigation using treated grey water**	**Xeriscape extensive (gravel + drought tolerant groundcover)**
Practice	**Weighting**	**Area (m2)**								
Surface System										
Artificial turf	**0.41**	-	-	-	-	-	-	-	-	-
Bare soil	**0.70**	-	-	-	177.43	-	-	-	-	-
Concrete	**0.33**	182.07	182.07	172.70	182.07	182.07	182.07	172.70	182.07	182.07
Gravel	**0.63**	-	-	-	-	-	177.43	-	-	112.27
Groundcovers	**0.67**	-	177.43	-	-	177.43	-	-	-	65.17
Lawn	**0.56**	177.43	-	177.43	-	-	-	177.43	177.43	-
Solar PV	**0.56**	-	-	-	-	-	-	-	-	-
Wetland (as water treatment plant)		-	-	9.37	-	-	-	9.37	-	-
Vegetation Unit										
Tree	**0.78**	-	43.39	43.39	43.39	-	43.39	-	-	-
Shading Unit										
Shading structure	**0.48**	-	-	-	-	-	-	-	-	-
Functional Surface										
Non-accessible vegetated area, visible from public pedestrian area (not intended for activity (e.g. ornamental garden)	**0.11**	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82
Connected soil	**0.22**	-	-	-	-	-	-	-	-	-
Unconnected - Deep soil (incl. Intensive green roof)	**0.07**	-	177.43	177.43	177.43	-	177.43	-	-	-
Unconnected - Shallow soil (incl. Extensive green roof)	**0.04**	177.43	-	-	-	177.43	-	177.43	177.43	177.43
Vegetation - drought tolerant species (e.g. xerophytes, etc.) - minimal irrigation	**0.33**	-	220.82	-	43.39	177.43	43.39	-	-	65.17
Vegetation - high efficiency irrigation with recycled/treated water	**0.22**	-	-	220.82	-	-	-	177.43	177.43	-
Vegetation - standard irrigation with potable water	**0.00**	177.43	-	-	-	-	-	-	-	-
Surface with high SRI (e.g. white roof)	**0.11**	-	-	-	-	-	-	-	-	-
Sum (Practice areas * weightings)		169.05	300.61	263.08	247.38	247.12	234.96	214.36	208.09	205.58
Plot area (excl Green Wall)		359.50	359.50	359.50	359.50	359.50	359.50	359.50	359.50	359.50
GAR-Score		**0.47**	**0.84**	**0.73**	**0.69**	**0.69**	**0.65**	**0.60**	**0.58**	**0.57**

APPENDIX 10 - APPLICATION OF THE TOOL - OLAVIDE PROJECT

			Non-water sensitive scenarios						Alternative surfaces		
		BC	**G4**	**G5**	**G6**	**G7**	**G8**	**G9**	**A1**	**A2**	**A3**
		Base case	**Lawn intensive and connected soil + trees**	**Lawn intensive + trees**	**Lawn extensive (BC) + shaded areas**	**Bare soil (neglected extensive green roof)**	**Gravel (neglected extensive green roof)**	**Lawn extensive (BC) + solar panels**	**Concrete with high SRI**	**Artificial turf**	**Concrete pavers**
Practice	**Weighting**	**Area (m2)**									
Surface System											
Artificial turf	**0.41**	-	-	-	-	-	-	-	-	177.43	-
Bare soil	**0.70**	-	-	-	-	177.43	-	-	-	-	-
Concrete	**0.33**	182.07	182.07	182.07	182.07	182.07	182.07	165.75	359.50	182.07	359.50
Gravel	**0.63**	-	-	-	-	-	177.43	-	-	-	-
Groundcovers	**0.67**	-	-	-	-	-	-	-	-	-	-
Lawn	**0.56**	177.43	177.43	177.43	177.43	-	-	177.43	-	-	-
Solar PV	**0.56**	-	-	-	-	-	-	16.32	-	-	-
Wetland (as water treatment plant)		-	-	-	-	-	-	-	-	-	-
Vegetation Unit											
Tree	**0.78**	-	43.39	43.39	-	-	-	-	-	-	-
Shading Unit											
Shading structure	**0.48**	-	-	-	71.41	-	-	-	-	-	-
Functional Surface											
Non-accessible vegetated area, visible from public pedestrian area (not intended for activity (e.g. ornamental garden)	**0.11**	22.82	22.82	22.82	22.82	-	-	22.82	-	-	-
Connected soil	**0.22**	-	69.15	-	-	-	-	-	-	-	-
Unconnected - Deep soil (incl. Intensive green roof)	**0.07**	-	108.28	177.43	-	-	-	-	-	-	-
Unconnected - Shallow soil (incl. Extensive green roof)	**0.04**	177.43	-	-	177.43	177.43	177.43	177.43	-	-	-
Vegetation - drought tolerant species (e.g. xerophytes, etc.) - minimal irrigation	**0.33**	-	-	-	-	-	-	-	-	-	-
Vegetation - high efficiency irrigation with recycled/treated water	**0.22**	-	-	-	-	-	-	-	-	-	-
Vegetation - standard irrigation with potable water	**0.00**	177.43	220.82	220.82	177.43	-	-	177.43	-	-	-
Surface with high SRI (e.g. white roof)	**0.11**	-	-	-	-	-	-	-	359.50	-	-
Sum (Practice areas * weightings)		169.05	218.59	208.22	203.33	191.38	178.96	172.80	158.18	132.83	118.64
Plot area (excl Green Wall)		359.50	359.50	359.50	359.50	359.50	359.50	359.50	359.50	359.50	359.50
GAR-Score		**0.47**	**0.61**	**0.58**	**0.57**	**0.53**	**0.50**	**0.48**	**0.44**	**0.37**	**0.33**