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Title: Appraising the psychological benefits of green roofs for city residents and workers

Authors: Kathryn J.H. Williams¹, Kate E. Lee¹, Leisa Sargent², Katherine A. Johnson³, John Rayner¹, Claire Farrell¹, Rebecca E Miller¹ and Nicholas S.G. Williams¹

¹School of Ecosystem and Forest Sciences, University of Melbourne; ²Institute for Housing and Urban Research; ³UNSW Business School | UNSW Australia; ⁴Melbourne School of Psychological Sciences.

Corresponding Author:

Professor Kathryn J.H. Williams

Email: kjhw@unimelb.edu.au

Postal address: School of Ecosystem and Forest Sciences, Baldwin Spencer Building, University of Melbourne, Parkville 3010.

Telephone number: +61 407814544

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Abstract

While a relatively small body of research links green roofs to psychological benefits such as aesthetic enjoyment and improved concentration, these outcomes are becoming important objectives in green roof design. Claims regarding benefits of green roofs are therefore often derived from research on psychological benefits of ground-level urban greenspaces. Compared with other urban landscapes, green roofs have limited space and accessibility, reducing the opportunity for physical exercise and the opportunity for larger masses of vegetation, particularly trees. Given these differences, there is a risk that the psychological benefits of green roofs are overstated or may only apply to a subset of green roof designs. Guidance for designing green roofs for psychological benefits may also be misleading if it fails to consider the unique green roof context. To address these challenges, we review research on psychological benefits of green roofs through a social-ecological lens on human-environment interactions. We consider how experiences of green roofs arise from an interaction between characteristics of the physical environment (including characteristics of green roof vegetation, wind patterns, and surrounding buildings), social climate (including social factors influencing access and use, and social norms for nature in cities), activities that can be undertaken on a green roof (such as exercise, socialisation, rest and relaxation), and individual resources and adaptation (for example, prior mood and opportunities to change environments to support individual needs). We explore how these factors interact with each other and with broader natural, built and socio-cultural systems that might encourage or inhibit opportunities to view, access, and enjoy green roofs. We conclude with recommendations regarding how green roofs can be designed to promote psychological benefits and identify future research needs.

Key words: restoration; aesthetic enjoyment; living roofs; roof top gardens; urban nature

Introduction

There is increasing awareness of the importance of urban nature for human well-being, with research demonstrating psychological benefits such as reduced stress and negative mood, improved attention control and renewed sense of vitality (Hartig et al., 2014). Consequently, urban greenspace design is becoming driven by goals of improving social and psychological outcomes for urban residents. This emphasis on psychological well-being is also evident for green roofs, where implementation may be motivated by potential benefits for nearby residents and workers in addition to the well recognised environmental benefits (Oberndorfer et al., 2007). While there is a significant body of research establishing how urban nature can promote psychological benefits (Hartig et al., 2014)– defined as changes in affect and cognition that are positively linked to well-being or function – there is reason to question whether these findings translate to the green roof context. Only a small body of research has directly considered the psychological benefits associated with green roofs, and generalisation of likely benefits from other contexts may not be appropriate given the significant differences in the ways people interact with green roofs compared with other forms of urban nature. While some green roofs clearly do promote psychological benefits (e.g. Lee et al., 2015; Mesimäki et al., 2018; White and Gatersleben, 2011), the circumstances under which this can occur are not well defined.

A considered appraisal of the psychological benefits of green roofs is needed because green roofs are a novel form of urban greenspace. Green roofs have existed in many different forms and across societies for long periods, and the benefits of green roofs for rainfall retention, reducing building energy use biodiversity and other ecosystem services are increasingly well understood (Lundholm and Williams, 2015; Williams et al., 2014). It is only relatively recently that they have been proposed as a way to ‘bring nature into cities’ for human benefit (see for example Loder, 2007). This understanding brings with it an expectation of the benefits to people long associated with parks and other forms of nature (Oberndorfer et al., 2007; Lee et al., 2015). Urban greenspaces have been linked not only to improved attention and mood, but to broader outcomes such as improved mental and physical health (Hartig et al., 2014), reduced aggression and crime (e.g. Kuo, 2003), improved productivity and creativity (e.g. Williams et al., 2018), and increased helping behaviours (e.g. Guéguen and Stefan, 2014). Although some have suggested green roofs will provide similar benefits (Oberndorfer et al., 2007), the ways that people experience green roofs may differ radically from the ways they typically experience parks and other ground-level landscapes. For example, while green roofs take many different forms, they are often not visible from ground level and visual access may be limited to people using the building the green roof is on or to those overlooking it (Sutton, 2014). Physical access can also be highly restricted, perhaps only to maintenance workers or to building users or to those with knowledge that the green roof exists (Yuen and Hien, 2005). Many green roofs are also relatively small, limiting the range of physical activities in which users can engage. Further, the types of ‘nature’ found on green roofs may be highly constrained by the size, environment or physical limitations of the roof. For example, the building weight-bearing capacity generally precludes planting of trees and shrubs (Weiler and Scholz-Barth, 2009). Research on psychological benefits of urban parks cannot therefore be simply generalised to green roofs.

We present a conceptual framework for analysing how green roofs can support psychological functioning in cities and apply this to review and reassess existing literature on the

psychological and social dimensions of green roofs. The scope of our analysis includes a diverse range of green roofs, including extensive (lightweight green roofs with shallow substrates and low vegetation such as succulents) and intensive (roof gardens that require deeper soils and may include taller vegetation such as shrubs and trees) green roofs (Oberndorfer et al., 2007). Rather than treating these as separate types of green roofs, we consider how their physical and social attributes interact with the needs and actions of individuals in these environments and how these interactions could shape psychological experience. As the existing literature on psychological benefits of green roofs is very small, we first draw on psychological and social-ecological research to present a consolidated framework for analysing human interactions with green roofs. We use this framework to evaluate how psychological benefits of green roofs are influenced by the physical environment, social climate, activity and individual resources and adaptation. Through this integrated analysis, we suggest an approach to developing a more comprehensive and credible understanding of the psychological benefits of green roofs.

Evidence for psychological benefits that may be provided by green roofs

Research on the psychological benefits of urban nature or greenspace generally – typically comprising ground level parks, gardens and street trees – suggests a wide range of psychological benefits that *may* be associated with green roofs, but there is limited empirical research directly linking these outcomes to green roofs. Compared with concrete or standard roofs, researchers have identified that green roofs provide greater aesthetic enjoyment and are perceived as having greater potential to support psychological restoration (Lee et al., 2014; White and Gatersleben, 2011). One study has demonstrated that micro-breaks spent viewing a green roof promote greater attention control (Lee et al. 2015). Another provides evidence that viewing a green roof can reduce perceived effort and consequently improve performance on work tasks (Lee et al., 2018). Studies from Canada and Finland demonstrate that many visitors to case study green roofs report positive aesthetic and restorative experience (Loder, 2014; Mesimäki et al., 2018). A post-occupancy evaluation of gardens in a hospital setting, including several roof top gardens, found psychological benefits for patients including emotion respite (Reeve et al., 2017). This study considers benefits more holistically (not just psychological outcomes). Within this context, the works report positive outcomes for some patients and staff users. Given the diversity of green roofs internationally, and the small number of studies on psychological benefits of green roofs (summarised in Table 1), this body of work must be considered promising rather than conclusive.

Two points can be made to place this small body of work in wider context. First, while the studies test only a small range of psychological benefits, those targeted are important because they might be considered ‘building blocks’ towards a much wider range of beneficial outcomes. For example, improved attention control – or the capacity to concentrate over sustained periods of time (Lee et al., 2015) – is important for problem solving and self-regulation (Kaplan and Berman, 2010) and so has been linked to improved creativity (Williams et al., 2018), work performance (Hartig et al., 1996), reduced aggression (Kuo and Sullivan, 2001a) and crime prevention (Kuo and Sullivan, 2001b). Similarly, aesthetic experiences – usually understood to refer to pleasant, relatively intense and memorable moments in the flow of life (Chenoweth and Gobster, 1990) – are linked to reduced negative

and enhanced positive affect, which in turn are associated with reduced rumination (Bratman et al., 2015) and greater likelihood of helping others (Guéguen and Stefan 2014). To our knowledge there is no direct basis for assuming green roofs can provide this broader range of outcomes, but research in other types of urban greenspace gives reasons for at least hypothesising this possibility.

Second, the psychological benefits of green roofs may differ according to green roof characteristics and the people experiencing it. For example, some green roof planting types are preferred over others and so may provide greater aesthetic and restorative benefits (e.g. Fernandez-Cañero et al., 2013; Jungels et al., 2013; Lee et al., 2014). There is also evidence that people experience green roofs in different ways. Loder (2014) showed that people hold different views on what nature in cities should be like, and that these views shape whether an individual considers green roofs to restore well-being. Similarly, surveys of visitors to a small, sparsely vegetated green roof in Finland showed that while most people reported positive experiences, around 11% found it disappointing or boring (Mesimäki et al., 2018). This variation in responses across green roofs and people is consistent with observations regarding other natural environments. It is well established that some natural environments provide more aesthetic enjoyment than others, with differences attributed to properties such as levels of complexity and coherence (Kaplan and Kaplan, 1989), cues of productivity and safety (Heerwagen and Orians, 1992) and socially learnt ideas of beauty (Nassauer et al., 2009). Similarly, natural environments vary in their potential to support psychological restoration, with more restorative environments being richer in qualities such as sense of fascination and being away from life's pressures (Nordh et al., 2009). A range of human characteristics such as knowledge, familiarity with the environment, and cultural views have also been shown to influence how individual people experience psychological benefits (e.g. Collado et al., 2016). Green roofs cannot be assumed to automatically provide psychological benefits given that characteristics of both the green roof and the people experiencing it will shape the likelihood of such outcomes.

In conclusion, there is emerging evidence that green roofs can boost aesthetic enjoyment, attention control, and provide restorative experiences. Green roofs may also have potential for a broader range of associated psychological benefits. However, these studies highlight the need to consider how the characteristics of green roofs and people might influence the psychological benefits of green roofs.

A conceptual framework for appraising psychological benefits of green roofs

Green roofs take many different forms and are designed to achieve different objectives, including storm water mitigation, reducing urban heat, enhancing urban biodiversity, noise reduction and/or social benefits (Shafique et al., 2018). Green roof classifications have often focused on technical characteristics, such as substrate depth and plant selection (Shafique et al., 2018). Technical characteristics have some bearing on human experience, but do not encompass all factors that may influence human experience. For example, some green roofs are accessible to visitors or residents, may include medium sized shrubs or even trees, or provide opportunities for activities such as gardening, yoga, or socialisation, but many do not. Therefore, the first step for comprehensively appraising psychological benefits of green roofs is to clarify which aspects of green roof design could influence the potential psychological

benefits. In this section, we introduce a general conceptual framework for understanding the psychological benefits of green roofs (summarised in Figure 1).

Our starting point for this conceptual framework is the human-environment interaction model (HEI) (Küller, 1991). The HEI model was developed to analyse how individuals emotionally experience and assess human-scale environments, for example, homes or workplaces. It first draws attention to multiple facets of human-environment interactions including attributes of the physical environment such as size, light, colour and complexity, attributes of the social climate such as crowding and friendliness, and attributes of the individual person such as personality and knowledge. The activities occurring in an environment are also critical; for example, an environment will be experienced very differently depending on whether people are there to rest, socialise or work. HEI proposes that environmental experience arises from interactions between these factors and cannot be attributed to one factor in isolation. The model is employed here primarily as a theoretical organising tool but has previously been employed to guide various field and experimental studies of emotional processes in environmental contexts (e.g. Johansson et al., 2012). In applying HEI to the psychological benefits of green roofs, the central (blue) circle of Figure 1 provides examples of factors that most directly shape *human-green roof interactions* such as the physical design of the green roof (e.g. scale, plantings, spatial layout, presence of surrounding buildings), qualities of the individual (e.g. level of fatigue, confidence with heights, understanding of urban nature), social environment (e.g. presence and friendliness of others), and activities (e.g. viewing, gardening or socialising).

The HEI model also suggests a process that shapes the emotions people experience in an environment (Küller, 1991). Feelings about environments – for example, aesthetic disgust or enjoyment, fear for safety, or relief from stress – arise when a person perceives and rapidly evaluates a change in their environment. On a green roof, this may occur when a person moves from a building interior onto the green roof: detecting strong gusts of wind one might feel vulnerable or energized; finding oneself alone on a roof top, rapid evaluation might result in feeling exhilarated or unnerved; scanning the surrounding cityscape from a green roof might feel oppressive or exciting. The range of potential responses to these experiences in part reflects individual dispositions and knowledge. A person might visit a green roof in a state of exhaustion, seeking an opportunity to recuperate, or they might seek stimulation through social interaction, new sights and sounds. Based on their individual evaluation of the situation, a person may take action or adjust their thoughts to maintain control of their circumstances. For instance, a person discomforted by wind or isolation might seek out a quiet and protected corner of the roof top or seek the company of others. Thus, people actively modify their experience, through the resources they bring to the experience (e.g. energy levels, knowledge and experience), and through actions or thoughts used to adapt or cope with the environment. There are physical and social constraints on whether and how people can adapt to the environment. For example, if the roof has no area protected from wind, a person might retreat indoors. Green roof designs that enable adaptation are more likely to support positive psychological outcomes.

To better understand the range of social, economic and technological factors that shape the psychological outcomes associated with a green roof, we place the HEI model within a broader social-ecological framework, represented in the outer green ring of Figure 1. This aspect of our own conceptual framework is inspired by the work of Hartig and colleagues on

the restorative opportunities afforded by homes or residences (Hartig et al., 2003). Hartig and colleagues (2003) first considered how residences can provide the experiences most closely associated with restoration including psychological distance from everyday demands as well as pleasurable psychological engagement through opportunities to read, socialise or dream. They then analysed (1) how broader cycles of activity – for example patterns of commuting, work, family commitments and sleep – can constrain or improve the opportunity for restoration in the home, and (2) how higher order social, economic and technological factors are changing these patterns of activity with consequences for restoration. For example, societal expectations regarding gender and caring roles can reduce the opportunities for rest within the home for some people, while urban design and technological changes have contributed to broader societal trends toward longer commutes as well as more people working from home. This work compellingly demonstrates how social, technological and economic factors are shaping the psychological benefits of one type of environment – the residence. In the same way, a realistic appraisal of the psychological benefits of green roofs can only be achieved by considering their social and ecological context. Much research on the psychological benefits of urban greenspace or nature is limited to the immediate interaction between person and place, but social-ecological frameworks challenge us to consider the broader system in which this interaction is situated (Stokols, 1992).

Social-ecological frameworks orient our attention to the broader systems in which the human-environment interaction is situated. These *social-ecological systems* incorporate natural, built and socio-cultural dimensions, positioned within the outer green ring of Figure 1. This framework invites us to think about how human-green roof interactions might be influenced by interactions between factors operating at a larger scale including:

- biotic and abiotic natural factors such as climate and regional vegetation that might influence roof top microclimates and plant survival;
- characteristics of built environment such as weight load capacity of the building that might constrain planting designs and access; and
- socio-cultural factors, such as organisational objectives that influence green roof design or job demands that influence access to the green roof.

Multiple higher order factors influence the nature of green roofs, how they can be used, and who can access them, which in turn shapes the opportunity for aesthetic and restorative experiences that support positive psychological outcomes. For example, climate change may increase the number of extreme temperature days occurring during summer and so reduce the time during which a green roof is comfortable for human use, which in turn would constrain opportunities for restoration through spending time on a green roof. Similarly, emerging building technologies might allow different deeper substrates to be used and so extend the kinds of plants that can be grown on roofs, which might promote more positive aesthetic experiences.

The relationship between higher order factors and the green roof is not uni-directional: introducing a green roof to a building will also change the social-ecological system in which it functions. The building-scale impacts of green roofs on natural and technical systems are relatively well understood, for example decreasing energy consumption and reducing the volume and frequency of stormwater runoff (Shafique et al., 2018). The influence of green roofs on socio-cultural systems is less well understood. At a building or organisational level

these influences could include changes to recreation or work practices – for example, encouraging greater lunch-time socialisation within an organisation might encourage collaboration and helping. Collectively, green roofs might also influence the cities beyond the building scale. Potential changes include a reduction in the urban heat island effect (Shafique et al., 2018) and increased property prices (Bianchini and Hewage, 2012) that can be experienced as a positive or negative impact by different people (Threlfall and Kendal, 2018).

In combination, HEI and the social-ecological frameworks provide a comprehensive conceptual framework for understanding the potential of a green roof to support positive psychological outcomes. In the following sections, we apply this conceptual framework to assess existing research on green roofs, using it to identify key considerations and points of leverage for assessing and promoting positive psychological outcomes.

Appraising psychological benefits of green roofs

What aspects of the physical environment of green roofs influence psychological benefits for city workers and residents?

While multiple aspects of green roof design are likely to be important for psychological benefits, the influence of green roof vegetation is perhaps best understood. At the simplest level, research demonstrates that any vegetation is better than a roof top with no vegetation (Lee et al., 2014; White and Gatersleben, 2011). It is worth pointing out however, that research on green roof psychological benefits has almost entirely been conducted with reference to the presence of living, healthy plants – something that cannot be assumed for all green roofs. One exception is Vanstockem et al., (2018) who found that gaps in vegetation cover and weedy plants negatively impact preferences). This is important, because green roofs can be hostile sites for plants (Farrell et al., 2012; Lundholm and Williams, 2015; Williams et al., 2010). In regions characterised by high temperatures and low annual or seasonal rainfall, only a narrow range of plants are likely to survive on green roofs, particularly if they are unirrigated. These are primarily plants with specific traits such as succulence (thickened and fleshy plant parts, that retain water) and low water use (Farrell et al., 2012; Rayner et al., 2016). A wider range of plants, including shrubs can survive in deeper substrates and with irrigation (Du et al., 2018), but plant selection will also be influenced by socio-cultural factors such as design objectives, maintenance regimes and availability of plants suited to the site. Successful green roof planting also depends on horticultural expertise during all phases of green roof planning, construction and maintenance (Dunnnett and Kingsbury, 2004). In short, while any living, healthy green roof vegetation has the potential to support positive psychological outcomes, realisation of this depends on outcome-focussed design process, appropriate plant selection, horticultural expertise and knowledge of and access to appropriate plant materials.

It is also likely that psychological outcomes will be influenced by planting design on the green roof, although we currently know very little about this relationship. Landscape design is generally built around a strong aesthetic narrative, balancing the visual attributes of plants, (colour, form, line and texture) and their composition (Robinson, 2016). Many green roofs however, are installed purely for environmental benefit with little attention to planting and

design outcomes (e.g. pre-grown Sedum mats). Studies have shown that roofs dominated by Sedums are less preferred than roofs with taller, greener, meadow-like vegetation (Fernandez-Cañero et al., 2013; Lee et al., 2014; White and Gatersleben, 2011). One study has found Sedum roofs are preferred over roofs planted with stoloniferous grasses (which spread from rhizomes, such as couch grass) (Jungels et al., 2013). A few studies have considered how plant combinations influence experience, with greater preference for plant variety in structure and colour (Fernandez-Cañero et al., 2013; Lee et al., 2014). One study suggests preference for green roofs that include flowering plants (Lee et al., 2014), consistent with wider literature on preferred landscape characteristics that demonstrates preference for landscapes with cues of productivity, such as flowering, fruiting, green plants with relatively large foliage, and taller height (Heerwagen and Orians, 1992; Kendal et al., 2012). This observation prompts an obvious challenge for green roofs as flowering plantings may not be feasible for green roofs characterised by high temperatures and low water resources (however, see Farrell et al., 2013 for suitable examples). In summary, research is required to understand what planting designs support positive psychological outcomes on green roofs and focus on identifying planting designs that are horticulturally viable in the challenging green roof environment and aesthetically appealing.

Beyond plant selection and design, research points toward a range of other properties of the physical environment that may be important for psychological benefits. Temperature and wind are very likely to influence benefits of green roofs, with residents in Singapore avoiding roofs perceived to be hot or windy (Yuen and Hien, 2005). At ground level, in small urban ‘pocket parks’, a sense of being away, an important component of restorative environments, can be promoted through enclosure by tall plants and surrounding buildings (Nordh et al., 2009); however, increased height of surrounding buildings has also been negatively linked to restorative potential (Lindal and Hartig, 2013). One consideration is that, viewed from the novel perspective of a green roof, surrounding buildings might promote a sense of fascination. In this case, façade ornamentation and variation of style across buildings in close proximity - positively related to restoration (Lindal and Hartig, 2013) – might be important considerations. From a green roof, city traffic and activity may be visible but from a distance; reduced noise and other stimulation might provide a sense of being away that is characteristic of restorative environments (Kaplan and Kaplan, 1989). To date, social research on green roofs has offered little to assist with understanding this possibility. Visitors commented on the view of city lights from two of the several roofs gardens on the Lady Cilento Children’s Hospital but provide little insights to how such views from green roofs might support psychological benefits (Reeve et al., 2017). Thus, temperature, wind, the dimensions and complexity of surrounding buildings, affordance of views are all likely to shape the psychological benefits of green roofs, but further research is required to understand whether and how this occurs.

What aspects of social climate influence psychological benefits of green roofs?

Research on experiences of green roofs highlights two aspects of social climate that are likely to shape potential psychological benefits. The first of these relates to opportunities to access and enjoy green roofs. Research on the benefits of urban nature is often predicated on the assumption of public open space being readily visible and accessible to members of the

public (e.g. Dzhambov et al., 2018). But even this body of work reveals complexities in the realities of access, since perceived access may not equate with actual access and perceived access may be influenced by social factors such as sense of belonging (Barbosa et al., 2007; Kessel et al., 2009). If access to public open space is a complex matter, access to green roofs is even more so. Green roofs are often on privately owned and managed buildings, and physical access is regulated, sometimes restricted to building residents or only to maintenance workers. Even when green roofs are accessible, they may not be used (Loder, 2014; Yuen and Hien, 2005). Researchers in Singapore explored residents' perceptions of green roofs through interviews and surveys and noted low visitation of accessible green roofs on Singapore public housing (Yuen and Hien, 2005). A key reason for this was a perceived lack of access, since it was often achieved via staircases requiring a reasonable level of physical fitness and knowledge of the green roof and how to access it. The authors concluded that "green roofs take open space out of public realm – into a more secluded community setting" (p. 274). Perceived access also may vary across different user groups. Davis (2011) noted that while hospital administrative staff considered roof top gardens very accessible, patients did not. Therefore, land ownership regimes, building access regulations, signage and visibility of the green roof all shape the potential of green roofs to provide psychological benefits.

The second aspect of social climate relates to social norms and discourses regarding nature in cities. For example, Loder (2014) found that social expectations of nature in cities shaped the ways that people in Toronto and Chicago experienced green roofs and their psychological benefits. Some people viewed prairie-style green roofs as interesting but messy and not preferred, while others viewed sedum green roofs as neat, but boring and therefore not appealing. Many people in this study also considered green roofs calming or softening in ways that reduced stress, and this seemed to be grounded in experiencing green roofs as a form of urban nature (Loder, 2014). But for some people, the form of nature offered by green roofs was not sufficiently immersive to be considered as nature, and they did not expect to derive any health benefits from the experience (see also Mesimäki et al., 2018, who observed similar variations in Finland). Prairie-style green roofs are used in some North American cities in part to promote use of local plants and biodiversity, but public understanding and appreciation of biodiverse roof top plantings varies. This may relate to broader environmental values and connections, a pattern resonating with evidence that Melbourne (Australia) residents reported feeling connected to nature tend to prefer taller vegetation on green roofs (Lee et al., 2014). Researchers in many parts of the world have identified similar tensions between 'messy' ecosystems and cultural expectations of neatness in cities, but also reveal social variation in these perceptions, and suggest strategies to help people see beauty in more 'natural' ecosystems (Nassauer, 1995; Williams and Cary, 2001).

Interestingly, Loder (2014) was able to observe how individual experience of green roofs changed over time and was shaped by broader socio-cultural factors. For example, access to green roofs promoted understanding of prairie-style roofs, as did education, direct experience, and watching change over seasons. Loder also placed individual beliefs about nature in the context of broader socio-cultural norms for nature and green roofs (Loder, 2007). Through analysis of policy documents and policy makers in Toronto and Chicago, she explored how policy approaches to green roofs both responded to, and reinforced, different visions of nature, either reinforcing or breaking down distinctions between cities and nature. While

Loder (2007) linked this analysis to the success or otherwise of green roof policy in the two cities, her work also serves to illustrate how the wider socio-cultural system influences more individual experiences and benefits of green roofs. At the same time, landscape designers have explored how green roof design can work to promote and influence appreciation of natural ecosystems within a social group (Sutton, 2014). This suggests how psychological benefits of green roofs are not only influenced by social climate but can actively shape social expectations of nature in cities over time.

Research to date has ‘scratched the surface’ of how social climate shapes interactions with green roofs, and consequently their psychological benefits. Existing research demonstrates that potential psychological benefits will not be experienced by all building occupants, and that a credible appraisal of these benefits must take visibility, access (real and perceived) and socio-cultural norms regarding urban nature into account. Other aspects of social climate are likely to be important, including commercial and other considerations that may shape design objectives. For example, Cinderby and Bagwell (2018, p.131) observed that for some companies the primary objective of green infrastructure is to promote their image as a ‘caring employer’. Further research is required to understand how a wide range of socio-cultural factors influence the psychological benefits of green roofs, including:

- how organisation objectives and culture influence green roof design objectives;
- how job roles and responsibilities inhibit or enable visual and physical access and use of green roofs;
- the influence of land ownership regimes, socio-cultural norms for restoration in cities and economic structures; and
- how these benefits and interdependencies operate for different members of society.

What activities influence psychological benefits of green roofs?

The activities in which people engage are a critical factor shaping the psychological benefits of environments (Küller, 1991), but very little green roof research addresses this issue. Some preliminary insights come from research in Singapore which found that key motivations for use of green roofs included outings for children, physical exercise, opportunities for peace and quiet (Yuen and Hien, 2005). In the context of people living in small apartments, green roofs provided a proximate destination for such activities, and were valued by respondents. These three activities are consistent with wider research in urban greenspace on how activity shapes psychological benefits. Physical exercise has been linked to stress reduction and increased creativity, with some indication that the activity may in fact be more influential than attributes of the environment (Dzhambov et al., 2018; Opezzo and Schwartz, 2014; Pretty et al., 2005). While intense exercise such as jogging is not likely to be afforded by many green roofs, activities such as yoga and gardening might be readily accommodated. Ghosh et al. (2016) highlighted the importance of gardening on green roofs as a proximate opportunity for food growing, social connection, learning and aesthetic enjoyment. Socialisation and opportunities for informal social contact are also understood to facilitate health and restoration benefits of urban greenspace (Dzhambov et al., 2018; Maas et al., 2009). Designing green roofs with spaces and facilities to support conversation and social gatherings (e.g. seating and barbeques) is therefore likely to enhance the psychological benefits. Accessing green roofs for peace and quiet may seem the least challenging activity to

support but requires careful design choices. Noise is a key consideration: some green roofs may be high enough above street level to reduce traffic noise, but the presence of air-conditioning units on green roof has a negative influence on enjoyment (Mesimäki et al., 2018). Similarly, in the constrained space of a green roof, it can be challenging to design privacy or space away from other people - although evaluation of roof top gardens in a healthcare setting demonstrates it is possible to achieve, even with constraints on plant selection (Reeve et al., 2017). Activities on green roofs could also be specifically designed to promote psychological benefits, for example tasks involving directed engagement with environment and other forms of mindfulness (Korpela et al., 2017; Lymeus et al., 2018), however the benefits of these practices have not yet been evaluated on green roofs. Given the constraints to restorative components of many green roofs (e.g. small physical size may limit scope to explore), this is an avenue of inquiry worth pursuing.

While green roofs can enable activities consistent with psychological benefits, these opportunities must also be understood within the context of wider activities and social climate. Just as restoration within the home is inhibited or enabled by cycles of work, recreation, and sleep (Hartig et al., 2003), restoration associated with green roofs is likely influenced by daily or week-long patterns of work and rest. Consider a green roof located on a multi-level commercial office building, where many workers undertake desk-based, cognitively effortful activities. Some workers may have window seats overlooking the green roof, while other workers may be located some distance from the roof. The worker with ready visual access has a resource they can draw on for maintaining concentration as even brief micro-breaks spent viewing a green roof have been linked to improvements (Lee et al., 2015). A worker without visual access may be able to walk to the window for a similar break, but workplace norms for short breaks may encourage or discourage such a restorative activity. If the green roof allows physical access, it has the potential to play further roles in supporting psychological restoration through lunch breaks, providing a 'green boost', potential physical exercise, socialisation or mindful connections with their environment. This will also depend on workplace norms for lunch breaks, and job demands that may limit time away from the desk (Troughakos et al., 2014). The opportunity for green roofs to support psychological functioning in the workplace is not limited to breaks. Researchers have found that the presence of workplace greenery while active work is being undertaken can promote creativity (McCoy and Evans, 2002). While untested in relation to green roofs, this warrants speculation that meetings held on or overlooking a green roof may promote creativity, or perhaps more positive social interactions - hypotheses that should be explored in future research.

In summary, green roofs may support psychological benefits by enabling positive activities such as socialisation, physical activity and mindfulness. But realisation of this potential depends on green roof design that affords space and amenities conducive to these, as well as patterns of activity that enable visual or physical access to green roofs for both rest and work. This suggests that green roof designers need to have a clear understanding of the organisational norms, roles and expectations that influence potential use of green roofs.

How do individual resources and adaptation affect psychological benefits of green roofs?

Individual contributions to human-environment interactions include the purposes, knowledge and resources people bring to the interaction and their actions and thoughts as they adapt and cope with an environment (Küller, 1991). In the first instance, there is evidence that people actively use nature in cities as part of a regulatory process: people spend time in nature to reduce stress and enhance a positive sense of self (Korpela et al., 2018; Korpela, 1989). This suggests that people might similarly go to a green roof to improve their sense of well-being. Observations of people using institutional green roofs provide some evidence of this, with reports of people choosing to spend an hour gardening on a roof top to improve their overall work day (Ghosh et al., 2016), or sitting in a small roof top garden to take respite from medical care (Reeve et al., 2017). Such benefits may occur in part because, compared with completely built environments, the natural elements of green roofs support a sense of coherence (and potentially fascination) that requires relatively little effort to process, and this facilitates lower effort expenditure on later work tasks (Lee et al., 2018). Literature on the role of environments in self-regulation highlights other characteristics that might support self-regulation processes, including opportunities for freedom and self-expression, pleasure, and belongingness (Korpela, 1989).

Very little is known about the ways that people might act to adapt and cope with the experience of the green roof itself. We are aware of instances where occupants of buildings with green roofs have modified the range of feasible activities. For example, the roof on the Council House 2 Building in Melbourne was originally designed as a space for socialisation, however building occupants later modified the layout to include elevated plots for growing vegetables, providing greater use and enhancing the social outcomes (John Rayner personal communication, 17/12/2018). Case studies have reported that the Lend Lease building in London provides ‘bug hotels’ and other elements that support biodiversity (Ghosh et al., 2016), which has encouraged building users to initiate citizen science-based research and nature gardening activities on the roof (John Rayner personal communication 17/12/2018). Further research is needed to better understand how green roofs can be designed to support individual and collective adaptation and coping within work and living environments. At a broad level, these current insights suggest that opportunities for individual and collective adaptation may be facilitated by participatory design processes that allow building users’ needs to be understood and considered, and through flexible designs accommodating future uses and needs.

While green roofs may be designed and modified to support individual adaptation and coping, it is important to note that green roofs may also have a wider influence on cities in ways that constrain these processes. Some large-scale urban greening programs have been linked to wider increases in property prices and gentrification and, in some cases, concern that lower income residents have been pushed out of a neighbourhood (Ichihara and Cohen, 2011; Threlfall and Kendal, 2018). Better understanding of these processes is required, but these trends suggest green roof planning at a city scale should be attentive to equity of outcomes (Wolch et al., 2014).

Implications and conclusion

Appraising the psychological benefits of green roofs

The first goal of this paper was to support more credible appraisal of the psychological benefits of green roofs. There is clear evidence that green roofs can support psychological benefits, but alongside this, considerable evidence that some green roofs promote these outcomes better than others, and some people may benefit more than others (Lee et al., 2015; 2018; Loder, 2014; Mesimäki et al., 2018). Noting the substantive distinctions between green roofs and other forms of urban greenspace, we consider this potential with attention to the social-ecological factors that shape human-green roof interactions. Our conceptual framework provides a robust basis for re-considering existing research on green roofs, drawing attention to how psychological benefits are influenced by factors at the roof, building and city scale, including characteristics of the physical environment and social climate, as well as activity, individual resources and scope for adaptation.

The review also highlights numerous gaps in our understanding of these complex relationships, summarised in Table 2. An important overall observation is the relatively narrow scope of the existing research on green roof psychological benefits, likely occurring because green roof research generally is at an early stage of development. The breadth of research on psychological benefits of green roofs is likely to broaden as the field develops, and the gaps identified in this review both identify and guide future research. As a general observation, research on landscape preference and restorative environments is often limited to observations of the immediate person-environment interaction, with little consideration of the broader social and ecological factors shaping this interaction at larger spatial and social scales (e.g. Lee et al., 2015). Research incorporating more qualitative and sociological approaches to understand human-environment interactions cannot precisely predict or test these psychological benefits but does provide important insights into broader societal factors shaping experience of green roofs (e.g. Loder, 2014). There is increasing recognition that aesthetic enjoyment and psychological restoration are shaped by wider social-ecological systems (e.g. Hartig et al., 2003). This underpins the importance of interdisciplinary approaches suited to appropriately considering ecological, physical, social and psychological characteristics of these interactions. Key research questions regarding these interactions relate to identifying green roof plants that are both horticulturally feasible and socially preferred, and links between psychological benefits and a broad range of socio-cultural factors, including land ownership, organisational norms, provision for roof top activities, and for adapting environments for future use. There is also a clear need for research to understand how green roofs individually or collectively impact on well-being of populations at a wider scale, whether positively through increased visual amenity, or negatively through changes to sense of place and belonging. At the same time, the review highlights the need for more basic psychological research to understand how green roofs affect a broader range of psychological outcomes. Creativity, productivity, and various forms of pro-social behaviours are plausibly linked to interactions with green roofs as a form of urban greenspace (Lee et al., 2018), but more research is needed to establish whether this is the case.

Designing green roofs for positive psychological outcomes

This review has clear implications for the design and planning of green roofs to provide psychological benefits for building occupants or surrounding residents. Throughout the

review, we have highlighted principles drawn from the conceptual framework and from existing research on psychological benefits of green roofs. These principles are summarised below in Figure 2, drawing attention to the multiple aspects of the physical environment, social climate, activity and individual adaptations that are salient to positive psychological outcomes from green roofs. Considering the many remaining questions regarding psychological benefits, these principles might serve as a preliminary guide to support those designing green roofs specifically for psychological benefits, to be improved as knowledge develops. Several aspects of this are noteworthy. First, much existing research has focused on understanding the kinds of plants that support aesthetic enjoyment (Fernandez-Cañero et al., 2013; Lee et al., 2014; White and Gatersleben, 2011). Plants and planting design are clearly key to the way that green roofs provide psychological benefits, but plants must be selected for horticultural suitability as well as aesthetic appeal. Additional aspects of the physical environment such as wind and noise, a supporting social climate, and scope for activities that support psychological function and adaptation are also critical. The interactions between design of the roof and socio-cultural factors are clearly important for planning: a roof may be designed for access and activity but remain unused if there is a poor match with organisational norms or workplace expectations. Considered together, this review suggests that design of green roofs for psychological benefits requires multiple forms of expertise. This includes architectural, engineering and landscape design with attention to matters of wind, noise, and heat, as well as weight-bearing capacity of the building, scope for irrigation and maintenance. Specialist horticultural knowledge is essential but is frequently missing from green roof decision-making, sometimes resulting in plant failure (Rayner and Williams, 2014). Also required is capacity for engaging with individuals and organisations to ensure design incorporates their needs and norms. Effective design of green roofs for psychological benefits also requires distinctive ways of considering the green roof in its wider landscape, with attention to the ways that surrounding buildings and viewpoints to and from the roof shape human experience of the environment.

Conclusion

Green roofs are a relatively novel and inadequately understood form of urban greening. This review was motivated by a concern that claims of psychological benefits associated with green roofs may therefore be overstated based on a small number of promising studies or overgeneralised from a larger body of research on psychological benefits of more traditional urban greenspace. We counter those risks by assessing how attributes of the physical environment, social climate, activity, individual resources and adaptation interact to shape experience of green roofs, and therefore potential psychological benefits. This analysis has revealed the complexity of experiences of green roofs, allowing us to better specify the circumstances under which green roofs may provide psychological benefits. While grassy and flowering vegetated roofs are most likely to support positive aesthetic and restorative outcomes, this is unlikely to occur without consideration of plant survival, impact of roof top heat and wind on human comfort, perceived access to the roof top, design fit with social norms for nature in cities, and provision for restorative activities and individual adaptation of the site. Transdisciplinary approaches incorporating horticultural, social science, design disciplines and user participation are required to achieve these outcomes. Of course, green roofs are unlikely to be the only form of urban nature for which claims of psychological benefits may be overstated. The principles we apply in this analysis - consolidated from well-established models of human-environment interactions and social-ecological systems – may therefore be beneficially applied to better understand the psychological benefits of other novel forms of green infrastructure in cities including rain gardens, pocket parks, green walls and green podiums.

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Table 1: Overview of studies of psychological benefits of green roofs

Article	Design	Sample	Sites or surrogates	Outcome measures
White and Gatersleben (2011)	Cross-sectional – quantitative questionnaire	188 residents of southeast UK	24 edited photographs (4 residence types; 6 vegetation conditions superimposed)	Preference; beauty; perceived restorativeness; affective qualities
Fernandez-Cañero et al. (2013)	Cross-sectional – quantitative questionnaire	450 residents of Seville, Spain	21 edited photographs (8 green roof types varying by extensive/intensive and vegetation)	Preference
Jungels et al. (2013)	Visitor (on-site) surveys – quantitative questionnaire	221 visitors to green roofs	7 green roof sites in North-East and Great Lakes region of USA	Aesthetic qualities
Loder (2014)	Semi-structured interviews – qualitative	55 office workers	Buildings with green roofs Toronto and Chicago	Aesthetic qualities, connections with nature, creativity, calmness
Lee et al. (2014)	Cross-sectional – quantitative questionnaire	274 office workers, Melbourne Australia	40 edited photographs (varying by plant life-form, foliage colour, flowering, diversity and height of vegetation)	Preference; restorative potential
Lee et al. (2015)	Experiment – quantitative	150 university students	40-second micro-break viewing photo-edited image of city view across either concrete or green roof	Attention restoration (Sustained Attention Response Task)
Reeve et al. (2017)	Post-occupancy evaluation – qualitative	Visitors who left comments in visitor books ('bench diaries')	Multiple gardens within Lady Cilento Children's Hospital, including a number of green roofs	Self-reported benefits (e.g. emotional respite)
Lee et al. (2018)	Experiment – quantitative	225 staff and students at university	Work break viewing roof top with either concrete or temporary meadow-style green roof	Tension; work performance
Mesimäki et al. (2018)	Visitor surveys – quantitative and some qualitative	178 visitors	Green roof site, Helsinki, Finland	Perceived restorative potential; aesthetic qualities

Table 2: Appraising psychological benefits of green roofs - Future research directions

What are the ecological traits of green roof plants that are aesthetically appealing?

How do views from green roofs influence experience and psychological benefits?

How do socio-cultural factors such as organisation culture and norms influence access, use and benefits of green roofs?

How do broader socio-cultural factors such as land ownership regimes shape the benefits of green roofs for different members of society?

How do activities such as gardening, exercise, socialisation, and mindfulness promote psychological benefits of green roofs?

Do work activities conducted or overlooking a green roof result in more positive social interactions and/or greater creativity?

What green roof designs facilitate individual and collective capacity to adapt and cope with work and living environments?

How do increasing numbers of green roofs at a city scale impact on the well-being of people from different socio-economic groups?

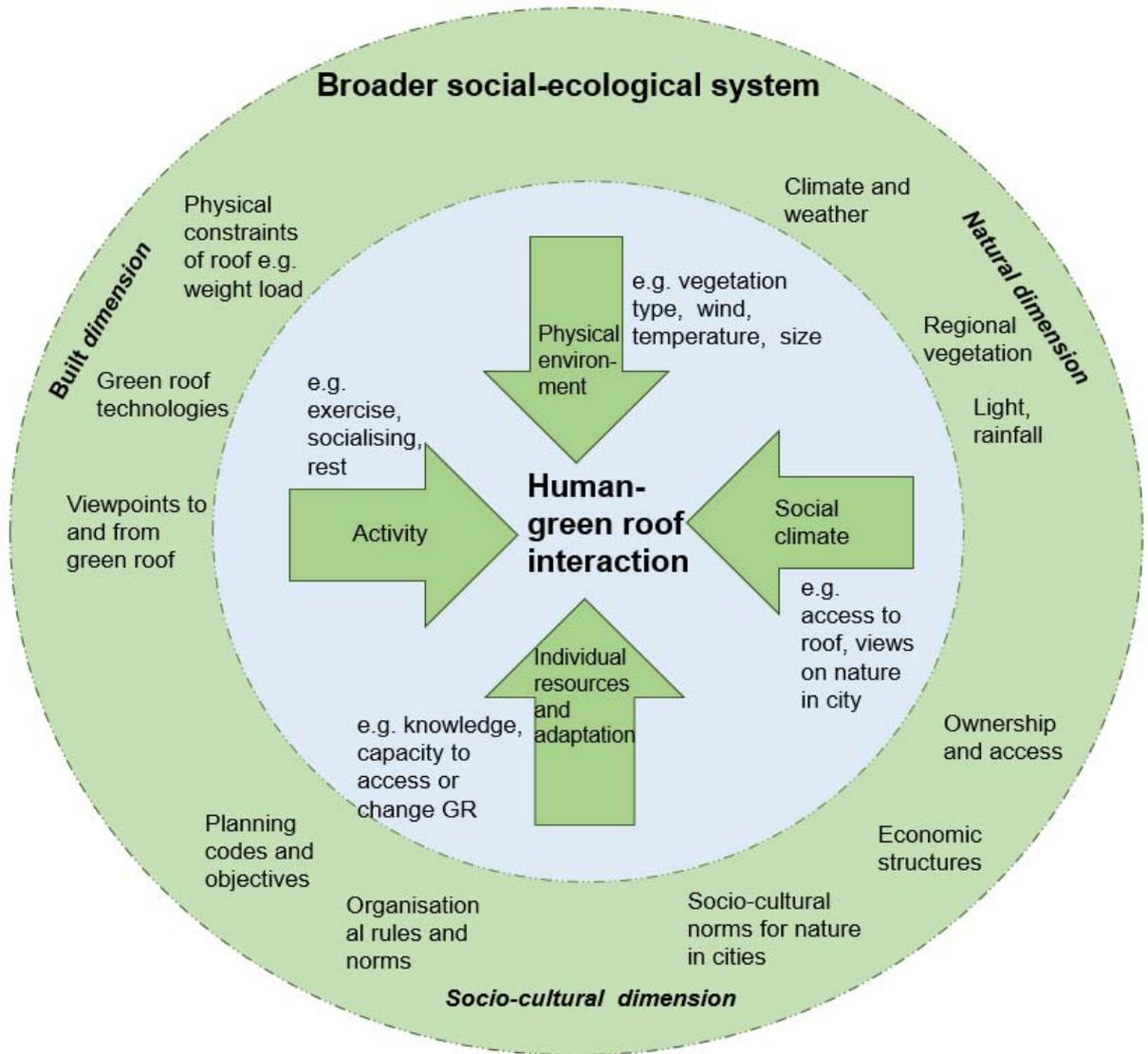


Figure 1: A general framework for considering aspects of human-green roof interactions within broader social-ecological systems.

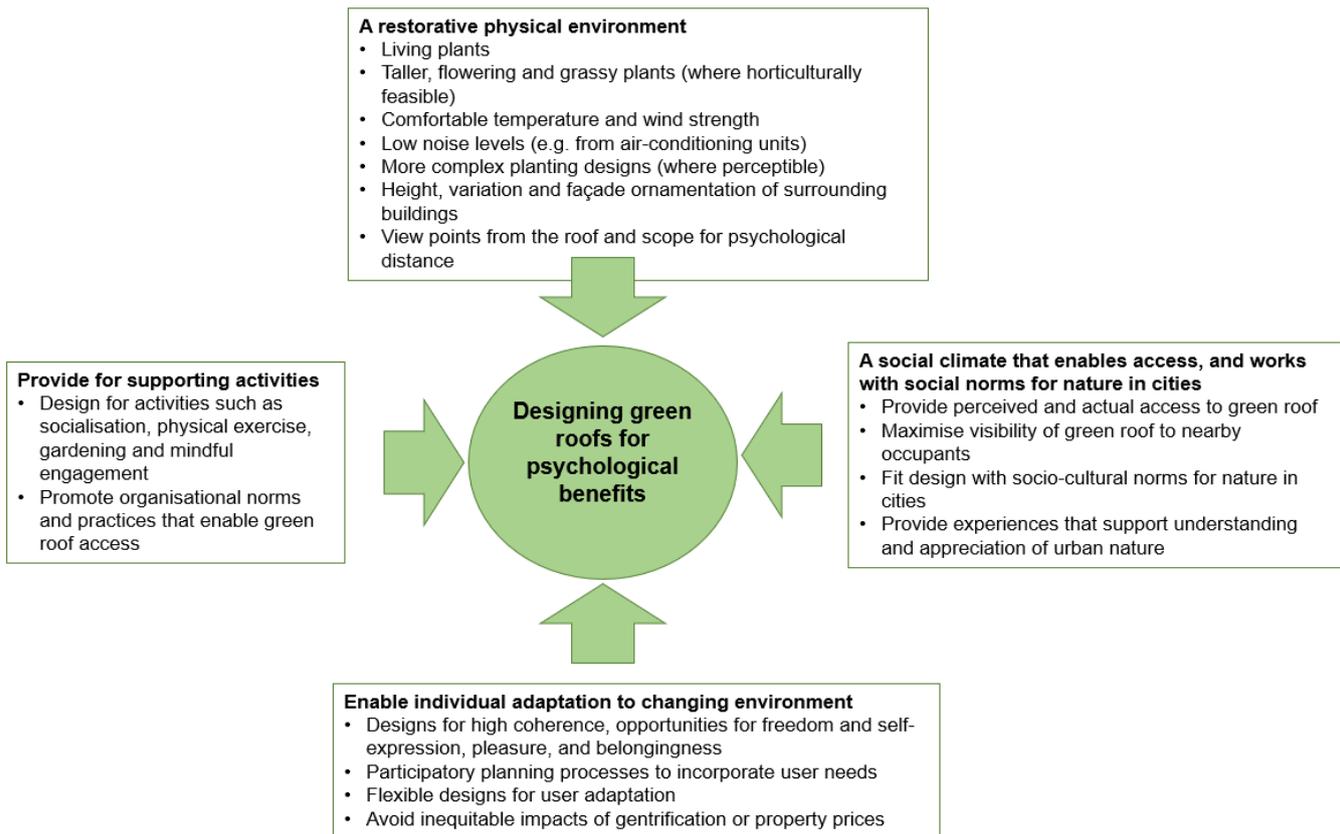


Figure 2: Designing green roofs for psychological benefits