



Perceptions of urban green infrastructures for climate change adaptation in Lausanne, Switzerland: unveiling the role of biodiversity and planting composition

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Abstract

This interdisciplinary study addresses the gap in understanding the perceptions of individuals regarding the role of urban green infrastructures (UGIs) in climate change adaptation, particularly with respect to biodiversity and planting composition. While climate-responsive design strategies commonly focus on increasing permeable green spaces and canopy coverage, the explicit consideration of biodiversity remains limited. By introducing a novel analytical framework, we investigate how residents in Lausanne, Switzerland, assess the impact of biodiversity and planting composition on the potential of UGIs to adapt cities to climate change. Through a questionnaire-based survey ($N=527$) and the use of photomontages and statistics, we examine the perceived potential of biodiverse versus uniform planting compositions to address climate change adaptation in Lausanne. Our findings demonstrate that respondents perceive biodiverse planting compositions as more successful strategies, attributing greater importance to trees in adaptation efforts, while overlooking the contributions of biodiverse herbaceous and shrub strata and soil permeability. Additionally, site characteristics associated with specific urban conditions significantly influence these perceptions. This evidence is subsequently discussed in two ways. Firstly, our analytical framework contributes to assessing the potential of UGIs in climate change adaptation, shedding light on the significance of planting composition. Secondly, the research emphasizes the need to transition from conventional climate-responsive approaches to more nuanced and sensitive methodologies that consider the multifaceted aspects of biodiversity. Such an approach holds promise for advancing the understanding of UGIs in climate change adaptation and informs future research directions.

Keywords Urban green infrastructure · Climate-responsive design · Climate adaptation · Biodiversity · Planting composition · Perception

1 Introduction

Climate change, in conjunction with urbanization, exerts an influence on the preservation of biodiversity by contributing to the loss of habitats caused by alterations in soil, air, and water, while simultaneously influencing the distribution and transmission patterns of

species within urban areas (Nowak 2010). Climate change affects all the levels of biodiversity, from biome to organism levels (Bellard et al. 2012), and modifies the web of interactions between species at the community level. Conversely, biodiversity also possesses the capacity to impact local urban climates. For example, the presence of trees and permeable green spaces can reduce surface temperatures, thereby enhancing the comfort of individuals experiencing urban open spaces (Robitu et al. 2006).

Due to these considerations, various stakeholders involved in urban governance are increasingly recognizing the value of integrating green urban spaces and features, such as parks, gardens, and street trees, as a means to adapt cities to climate change. These components are commonly referred to as urban green infrastructure (UGI) and offer benefits through ecosystem services, including microclimate regulation (Lovell and Taylor, 2013). UGIs serve as key structures through which biodiversity can influence local climates. Consequently, the use of UGIs to combat adverse microclimate effects and enhance urban resilience has prompted design professionals and scholars to develop climate-responsive design guidelines for cities (Berger et al. 2020; Brown 2010; Klemm et al. 2017).

Climate-responsive design leverages UGIs and primarily relies on two overarching strategies. The first strategy involves the expansion of green permeable spaces, while the second emphasizes the planting of trees to increase canopy coverage in areas exposed to high solar radiation (Klemm et al. 2017). Existing literature on climate-responsive design primarily focuses on the analysis of these two strategies without explicitly considering their association with biodiversity. However, in this article, we contend that a biodiversity-oriented perspective can enrich climate-responsive design, thanks to the notion of planting composition. Planting composition refers to the arrangement of plant species across multiple strata and is contingent upon specific urban conditions and streetscapes (Othman et al. 2015). Planting compositions that present high levels of biodiversity could be associated with climate-responsive design to some extent, since diverse tree species are associated with varying canopy covers (Madonsela et al. 2018) and diverse plant species exhibit different effects on soil permeability (Semwal et al. 2020). Nonetheless, scholarly research on the relationship between biodiverse planting composition and climate-responsive design remains limited.

However, climate change issues and the potential of biodiverse climate-responsive design to address them are often not widely recognized by civil society due to perceptual barriers (de Munnik and Lenzholzer 2020). Perceptual barriers refer to gaps in understanding or misperceptions stemming from the complex, uncertain, and often invisible nature of the causes of climate change (Nicholson-Cole, 2005). However, the perception and acknowledgment of these issues play a crucial role in fostering public engagement and support for adaptation measures (Sheppard 2015). Consequently, urban municipal governments employ various communication tools and visual strategies to raise awareness about climate adaptation measures (Sheppard 2012). Previous studies have employed graphs, abstract diagrams, maps, and photorealistic imagery to illustrate the impacts of climate change to the general public (O'Neill and Graham, 2016; Glaas et al. 2017; Wardekker and Lorenz, 2019; de Munnik and Lenzholzer 2020). Moreover, highlighting visual representations of solutions rather than solely focusing on climate issues has proven to be effective, as individuals tend to respond more positively and feel empowered when presented with positive design outcomes (Shaw et al. 2019).

The adoption of specific visual strategies would thus enhance the perception of urban green infrastructure (UGI) and its role in city adaptation through climate-responsive design. While a few studies have examined how visual strategies can improve public acceptance of climate-responsive projects and design solutions (de Munnik and Lenzholzer

2020), these studies have not specifically focused on UGIs and planting composition. Therefore, the primary objective of this article is to evaluate the impact of planting composition on the perception of UGIs' potential contribution to adapt cities to climate change. To achieve this objective, we employ photorealistic imagery of climate-responsive design scenarios as a framework for analysis.

Therefore, this research focuses on the analysis of climate-responsive design scenarios implemented in the city of Lausanne, Switzerland. First, it provides an overview of the theoretical advancements concerning the perception of biodiversity through visualization strategies. In doing so, a novel analytical framework is proposed to evaluate the perception of the role of UGIs in city adaptation to climate change. The methodology section outlines the selection of six specific sites in Lausanne, each associated with distinct climate-responsive design and planting composition strategies tailored to street and open space conditions. Additionally, these scenarios are assessed through a questionnaire. The statistical analysis of responses from Swiss residents ($N=527$) is then discussed from two perspectives: first, how our analytical framework contributes to assessing the potential of UGIs in adapting Lausanne to climate change, and second, why transitioning from climate-responsive approaches to more sensitive approaches opens up new avenues for research.

2 UGI perception and climate-responsive design visualization: theoretical approaches

2.1 Dynamics of biodiversity perception: the need for understanding and exploring one's environment

The concept of biodiversity perception has been previously explored in the literature, originating from Kaplan and Kaplan's application of the information processing theory to the perception of nature (1989). Their research on the experience of nature indicates that individuals tend to perceive their environment based on specific preferences related to two primary categories of human needs and activities: understanding and exploration. The need for understanding is associated with comprehending what is happening in the environment. It relies on certain physical attributes that contribute to individuals' understanding of their surroundings by establishing coherence within a given space. Understandable spaces are organized into distinct units, offer a sense of order, direct attention, facilitate orientation, and aid in wayfinding. Conversely, the need for exploration is a crucial aspect of uncovering further insights about the environment, expanding an individual's capacity to comprehend complex situations, or deepening their understanding of a familiar setting. Exploration involves delving into the intricacies of a space and the anticipation that one can acquire more knowledge about their surroundings. The perception of scene richness, which refers to the presence of a diverse array of natural elements, reflects the sense that numerous activities are taking place and suggests that there is much more to be considered and explored within the environment.

While the information processing theory was established four decades ago to examine the perception of nature more generally, it continues to be widely applied in studies specifically focused on biodiversity perception. In their review of urban biodiversity perception and valuation, Botzat et al. (2016) noted that many of the analyzed studies used the term "perception" interchangeably with attitude, opinion, or impression. However, they propose that biodiversity perception refers to "to the act of perceiving biodiversity in its literal sense

of processing information with all senses” and can be defined by two main variables: perceived site condition and legibility and self-estimated species richness. Therefore, several studies examined by Botzat et al. (2016) are grounded in the information processing theory applied to nature perception. The variable of “site condition and legibility” can be associated with the need to understand one’s environment, while the variable of “self-estimated species richness” relates to the need for exploration. It is worth noting that most studies utilizing this theoretical framework primarily focus on the ecosystem level of biodiversity (Nassauer 1995; Müller et al. 2013), including UGI.

However, analyzing the perception of UGI through the lens of climate change challenges this framework, as climate change is a dynamic phenomenon that alters the environment, implying a change in perception over time.

2.2 Visualizing UGI through climate-responsive design scenarios

To address this perceptual challenge, research has predominantly employed visual communication techniques, such as maps, 2D and 3D renderings (Burch et al. 2009; Berger et al. 2020; Glaas et al. 2017; Mees et al. 2018), and animated photorealistic imagery (de Munnik and Lenzholzer 2020), to depict urban climate phenomena and climate-responsive design solutions. Sheppard (2012) asserts that well-crafted imagery can effectively convey design options to communities for adapting to their environment and demonstrate the outcomes of such actions, thereby motivating them to engage in climate adaptation efforts. In this regard, Sheppard developed an awareness-to-action framework comprising five guidelines to create impactful visualizations related to climate adaptation:

- “Clarity” emphasizes the fact that climate change should be easily seen and understood;
- “Connectivity” contributes to linking climate change impact to context, place, and people;
- “Engagement” is associated with visualizations that are interesting and inclusive;
- “Trust” relates to honest and verifiable visualizations;
- “Feasibility” is associated with practical, cost-effective climate adaptation designs shown in the imagery.

These guidelines also imply that urban environments should be depicted over time, illustrating situations before and after the implementation of solutions.

They also exhibit some alignment with Kaplan and Kaplan’s theoretical framework on nature perception. The concepts of “Clarity,” “Connectivity,” and “Trust” correspond to the need to understand one’s environment, while “Engagement” and “Feasibility” can be associated with the need to explore. While Sheppard’s framework (2012) primarily focuses on the perception of carbon emissions through specific visualizations associated with climate change, this study highlights its potential for assessing the perception of urban green infrastructure (UGI). Table 1 demonstrates how the combination of Kaplan and Kaplan (1989) and Sheppard (2012) approaches contribute to the development of a new framework adapted to the perception of UGI through the lens of climate change.

By integrating these two approaches, this study introduces a novel analytical framework that aims to enhance the understanding of local populations regarding the role of UGIs in adapting cities to climate change. Through the case study of Lausanne, Switzerland, this research contributes to the examination and application of this new framework.

Table 1 Combining information processing theory and the awareness-to-action framework: a new conceptual approach to analyze UGI perceptions using visualization

Information processing theory (Kaplan and Kaplan 1989) applied to biodiversity (Botzat et al. 2016)	Awareness-to-action framework (Sheppard 2012)	UGI perception and visualization framework
Need to understand (Kaplan and Kaplan) > Site condition and legibility (Botzat et al.)	Clarity	The depicted UGI is organized into distinct units, facilitating a sense of order, directing attention, and aiding in orientation and wayfinding
	Connectivity	The depicted UGI is associated with familiar contexts that enable individuals to better comprehend and establish connections with their environment
	Trust	The depicted UGI is portrayed realistically and verifiably, enhancing trust and promoting a deeper understanding of the environment
Need to explore (Kaplan and Kaplan) > “self-estimated species richness” (Botzat et al.)	Engagement	The depicted UGI is engaging and diverse, representing a wide array of natural elements that can be experienced by individuals from different backgrounds
	Feasibility	The depicted UGI is practical and encourages easy exploration of the environment, catering to the needs of diverse individuals

3 Methodology

3.1 Addressing biodiversity and climate change adaptation in Lausanne

The city of Lausanne, situated on the shores of the Lac Léman, is the largest city in the Swiss canton of Vaud. It is positioned between the Alps and the Jura Mountains and spans an area of 41.8 km². Of this total area, densely built regions account for 39.5%, forests cover 38.8%, agricultural land occupies 14.3%, and parks and other green recreational spaces make up 7.4% (Ville de Lausanne 2018). However, these statistics do not encompass smaller-scale UGI elements such as private green spaces or gardens, tree alignments and hedges, and small neglected green spaces, which are also crucial for biodiversity and climate change adaptation. To leverage UGIs for climate change and biodiversity conservation, the city has implemented several programs, namely the Canopy Objective and the Climate Plan.

The Canopy Objective (Ville de Lausanne 2021b) is part of the broader Lausanne Climate Plan (Ville de Lausanne 2021a) and focuses on climate-responsive design strategies primarily through increasing the number of trees and canopy cover in the city. Lausanne currently has approximately 8000 avenue trees, 80,000 trees in parks, and 800,000 trees in forests. The existing canopy cover represents around 20% of the city's land area. The municipal authorities aim to raise this coverage to 30% by 2040. Achieving this objective entails increasing the number and size of trees, particularly in public open spaces where favorable conditions for tree growth exist and where the municipality has the authority to take action. The city has defined six climate-responsive strategies utilizing UGIs based on the morphology of streets and other open spaces, as described in Table 2.

The Municipality of Lausanne has also embraced a “Nature in the City” policy since 2012 to enhance the integration of biodiversity into urban development. This policy focuses on various ecological aspects, including the maintenance of green spaces, tree protection, green roof development, the establishment of ecological networks and native hedges, and raising awareness among Lausanne residents about ecological practices. Implemented by the Parks and Estates Department of the Housing, Environment, and Architecture Directorate, the Nature in the City policy also aims to promote soil permeability. The “strategy for the requalification of public spaces and response to four postulates relating to the redevelopment of public spaces” (Affolter 2021) highlights the importance of soil permeability in mitigating the impacts of extreme weather events.

Although these programs reflect city-level public policies and planning strategies, their implementation in smaller-scale urban design projects is not yet fully realized. It is within this context that the present research is conducted.

3.2 Sites selection

In order to assess residents' perception of the role of UGIs in adapting the city to climate change, this study employed various visualizations of climate-responsive design scenarios based on the analytical framework outlined in Table 1. Six specific sites were chosen to represent the six climate-responsive design strategies outlined in the Canopy objective (Fig. 1), as defined by the Municipality of Lausanne. The selection of these sites was conducted in collaboration with three local experts specializing in urban planning, design, and green space maintenance in Lausanne. These sites were deemed suitable by the city for developing future climate-responsive design strategies that cater to the specific urban conditions of the area.

Table 2 Canopy objective's climate-responsive design strategies in relation to UGI according to Lausanne's street morphologies

Site number	Street morphology	Associated climate-responsive design strategy in relation to UGIs
S 1	Green veins along the main axes	Trees should be planted continuously to create eco corridors and landscape continuities across different urban fabrics at the city scale
S 2	Continuous building district streets	Trees create more or less dense sequences and provide a planted street atmosphere thanks to the diversification of species and plant strata
S 3	Neighborhood streets along groups of buildings	Trees and other greeneries should be planted in several strata to give a park-like atmosphere, thanks to varied volumes, shapes, and rhythms
S 4	Streets in residential areas	Trees and greeneries give a garden-like atmosphere, creating continuities or sequences when the size of the street allows it. The overflow of private plantings onto the street should be allowed
S 5	Neighborhood streets close to parks and forests	Arborization is encouraged through the extension of the forest/park atmosphere to the street while avoiding competition between park and sidewalk trees
S 6	Old town streets and squares	Large solitary trees or groups of trees should punctuate the street and the squares, especially at dilations and intersections

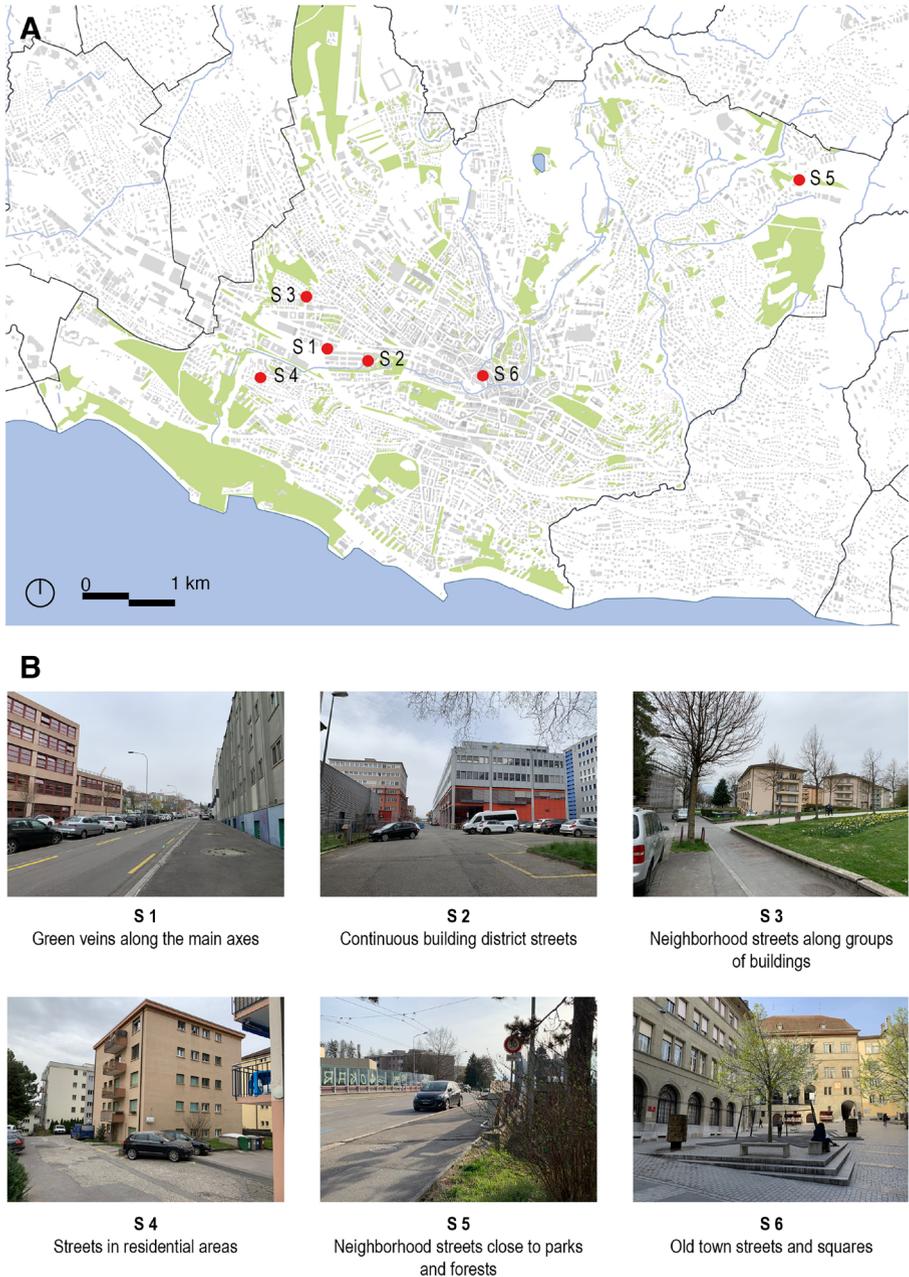


Fig. 1 Map of the sites' location (A) and presentation of the sites (B)

To assess to which extent biodiverse planting compositions can be perceived as an effective way to adapt cities to climate change by the respondents, we created two photomontages of climate-responsive design scenarios for each of the selected sites (Fig. 2). These

design scenarios aimed to enhance soil permeability and increase canopy coverage by employing two distinct planting composition strategies. The first photomontage depicted a relatively uniform and limited plant species composition, while the second photomontage showcased a greater diversity of species and plant strata, emphasizing a biodiverse planting composition approach.

The produced photomontages are based on the framework we presented in Table 1 (Fig. 3). These visualizations were preceded by a short text on the potential impacts of climate change in Switzerland to increase “Trust”.

Subsequently, we utilized the photomontages to assess permeable surfaces and canopy coverage (Fig. 4). For permeable surfaces, we identified various soil types visible in the photomontages (such as asphalt, pavings, lawns, and planted flower beds) and assigned specific permeability percentages to each type. For example, asphalt was deemed completely impervious (0% permeable), while permeable pavings and stabilized soils were considered semi-permeable (with permeability ranging from 10 to 50% depending on the soil type), and flower beds and lawns were recognized as permeable (100% permeable). We then delineated each of these surface types on a map and calculated the average soil permeability for each site using the formula:

$$(\text{Average total permeable area}) \div (\text{Total terrestrial area of the site}) \times 100\%$$

Regarding canopy coverage, we mapped the trees depicted in the photomontages onto a separate map. We represented the canopy coverage associated with each individual tree using circles and calculated the canopy index for each site using the formula:

$$(\text{Tree canopy cover}) \div (\text{Total terrestrial area of the site}) \times 100\%$$

The examination of these indices provided a means to quantify the planting composition potential for each site. As an illustration, the site n°6 corresponds to a historic center square with limited possibilities for making the soil more permeable, therefore reducing planting composition opportunities. Consequently, developing a climate-responsive design scenario that emphasizes the augmentation of herbaceous and shrub strata becomes more challenging. Therefore, this limitation may influence the perception of the role of UGIs in adapting this particular site to climate change.

3.3 Survey and data collection

The photomontages therefore enlightened how different planting compositions were used to develop specific climate-responsive scenarios adapted to various streets and open spaces conditions in Lausanne. In order to examine these design scenarios and gain a deeper understanding of how respondents perceive the role of planting composition in adapting cities to climate change, a survey was designed to reach residents aged 18 and above.

The survey comprised two sections. The first section sought to evaluate respondents’ perception of the sites’ potential for hosting biodiversity, considering both the uniform and biodiverse planting composition strategies, as well as how these planting compositions contributed to adapting the sites to climate change. For each photomontage, respondents were asked two questions pertaining to the design’s potential for hosting biodiversity through urban green infrastructures (PB) and for adapting the city to

climate change (PAC). Respondents were instructed to rate the PB and PAC of each photomontage using a Likert scale ranging from 1 (low potential) to 5 (high potential).

The second section of the survey aimed to gather demographic information, including age, gender, and geographical origin.

The survey was distributed over the course of 1 month in 2022 through various channels, including the following:

1. A general mailing list of the University of Lausanne.
2. A post on the website of the *Observatoire universitaire de la ville et du développement durable*.
3. A targeted mailing campaign to the 17 *Maisons de Quartiers* (neighborhood community centers) in the city of Lausanne. Five of these centers posted the survey on their social media platforms.
4. A targeted mailing campaign to the 29 associations of the Lausanne Nature Platform.

At the conclusion of the survey campaign, a total of 1237 responses were collected. However, upon examination, 698 of these responses were found to be incomplete and were excluded from the study. Among the remaining 539 completed responses, 12 were further excluded as the corresponding respondents were residing outside of the country and did not have firsthand experience with the streetscapes of Lausanne. As a result, the final sample size considered for this study consisted of $N=527$ responses. Table 3 provides an overview of some characteristics of the sample.

In terms of gender representation, females were overrepresented in the sample, accounting for 62.8% of the respondents, compared to the effective gender proportion in Switzerland of 50.4%. Additionally, there was a 1.7% discrepancy due to the inclusion of the “other” gender category, which was not accounted for in the Swiss census.

Regarding age distribution, participants in the study ranged from 18 to 65 years and older. Notably, younger age categories were overrepresented, with 34.5% of respondents falling in the 18–24 age group and 24.7% in the 25–34 age group. These percentages exceed the age proportions in Switzerland, which are 7.5% for the 18–24 category and 13.1% for the 25–34 category. This suggests that individuals under the age of 18 were not invited to participate in the survey and that a significant portion of the respondents were likely students from the University of Lausanne.

Furthermore, 36.2% of the respondents reported living in Lausanne, indicating that the majority of the participants may not have had regular exposure to the specific sites under investigation in the study.

3.4 Data analysis

The data collected from the survey were analyzed using SPSS in two steps.

In the first step, the average scores for the perception of IGUs’ potential to host biodiversity (PB) and adapt the city to climate change (PAC) were calculated for each photomontage. These scores were then analyzed for each site and each planting composition scenario (uniform or biodiverse) to determine the impact of these factors on the perception of the role of IGUs in adapting Lausanne to climate change.

In the second step, the correlation between planting composition, soil permeability, and canopy cover was examined to understand how these variables influenced respondents’

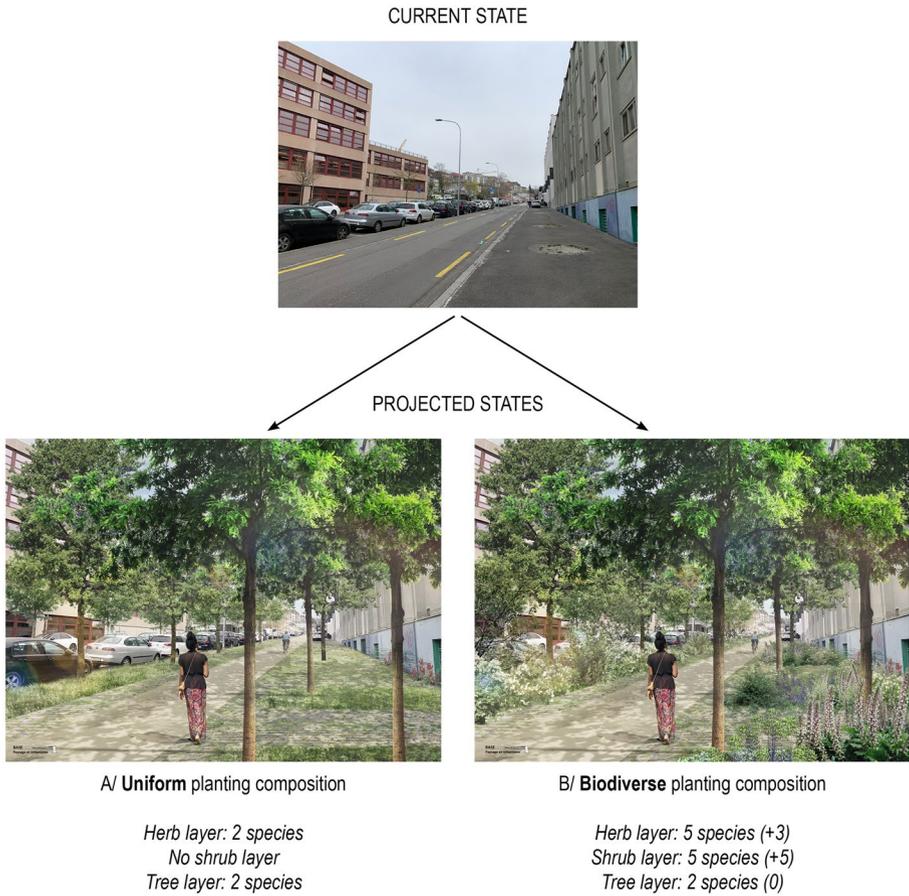


Fig. 2 Protocol: Sébeillon as an example

perceptions. Pearson’s correlation coefficient (r) was used to measure the strength of the statistical relationship between two variables. The coefficients were calculated using SPSS, and the strength of the correlations was interpreted based on the framework developed by Akoglu (2018) as presented in Table 4.

A total of 8 Pearson correlation tests were conducted to examine the relationships between the PB and PAC scores obtained from the two planting composition strategies and the permeability and canopy indices. These correlations were used to assess the extent to which a specific planting composition strategy contributes to climate change adaptation. For instance, a strong correlation ($r > 0.5$) between the PAC scores obtained for the biodiverse composition scenarios and the permeability indices associated with those scenarios would indicate a significant relationship. This relationship suggests that respondents perceive a significant contribution of high soil permeability resulting from biodiverse planting compositions to the adaptation of Lausanne to climate change.

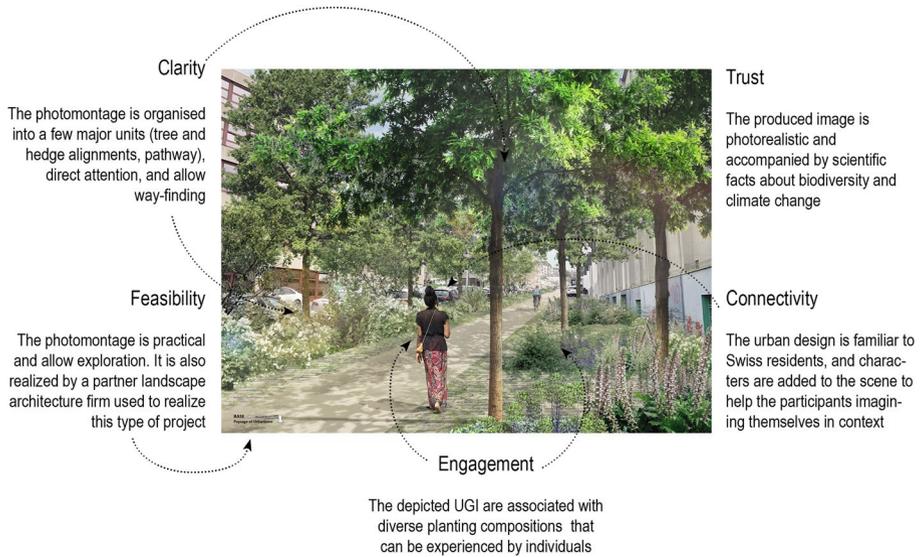


Fig. 3 Example of a photomontage highlighting the framework of analysis

4 Results

4.1 Perception differences in climate-responsive design scenarios across diverse urban sites

An initial examination of the average scores derived from the survey data (Fig. 5A and B) reveals that variations in perception are contingent upon the specific site conditions and the corresponding climate-responsive design strategies employed.

Significant differences in perception scores between the initial and climate-responsive design scenarios can be observed across all sites. In the case of S1, notable discrepancies in perception scores for the potential to host biodiversity (PB) and adapt the city to climate change (PAC) are observed, with an increase of 2.2 points for the uniform planting composition scenario and 2.5 points for the biodiverse planting composition scenario. Conversely, for S3, these differences are comparatively smaller, with an increase of 0.9 points for the uniform planting composition and 0.7 points for the biodiverse planting composition. These findings could be attributed to the initial planting composition of the selected sites. S1, characterized by predominantly asphalted areas and commercial buildings with limited UGIs, exhibits a deficient initial site condition in terms of planting composition. In contrast, S3 represents a low-density neighborhood with a well-endowed public park and tree alignments, resulting in relatively higher PB and PAC scores for the initial site condition, albeit not being highly biodiverse.

In contrast, S4 and S6 initially exhibit limited UGIs. S4 primarily consists of bare streets and parking lots, while S6 is situated in the impermeable historic center of Lausanne. Despite both planting composition scenarios significantly increasing the presence of permeable spaces, trees, and other plant species in these sites, respondents perceive these



Fig. 4 Going from visualization (A) to plan and indices calculation (B)

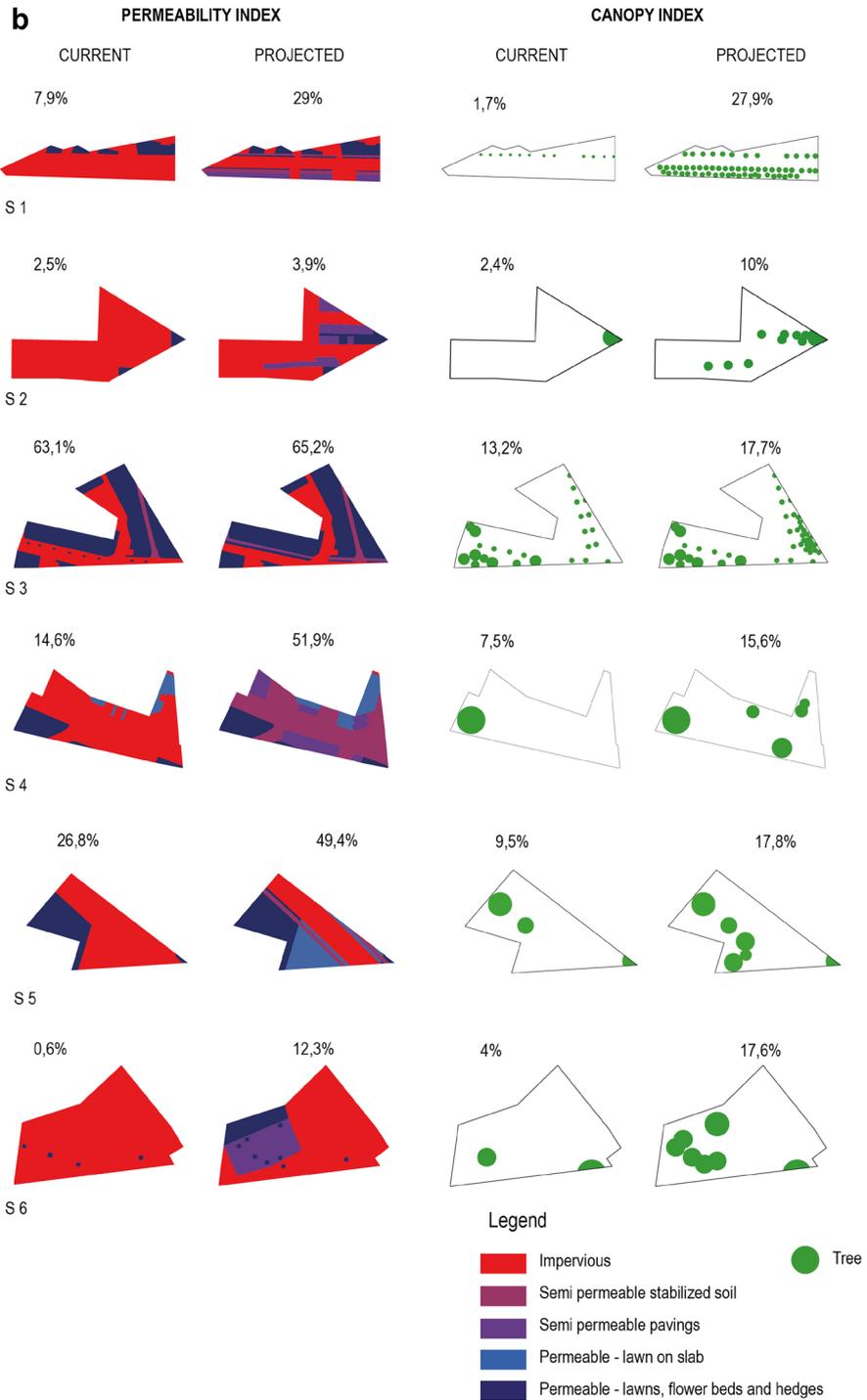


Fig. 4 (continued)

improvements less favorably. The average discrepancies in PB and PAC scores are +1.3 points and +1.2 points, respectively, for S4, and +0.7 points and +0.8 points, respectively, for S6. Moreover, for both sites, the PB score is lower than the PAC score in the biodiverse planting composition scenario, whereas it is higher for the other sites, regardless of the initial conditions or planting compositions. This observation suggests that in spatially constrained and highly impermeable urban contexts characterized by small open spaces surrounded by tall or medium-height buildings, individuals perceive a lesser potential for sites to be adapted to climate change through UGIs. Additionally, S4 shares similarities with S6 in terms of urban morphology, including medium to high-rise multifamily buildings with mostly impermeable and unplanted small courtyards. This distinction is not present in the other sites, which feature more UGIs and open landscapes, particularly in S3 and S5.

4.2 Overlooked contributions of biodiverse herbaceous and shrub strata

Pearson correlation analyses were conducted to investigate the relationships between the perception scores for PB and PAC, and the canopy and soil permeability indices. A total of eight Pearson tests were performed to examine the influence of the measured indices on PB and PAC perception. The resulting correlation coefficients for each test are presented in Table 5.

The findings presented in Table 5 reveal that the majority of the correlations between the perception scores and the canopy and soil permeability indices are of moderate strength, with higher Pearson's r -values observed for the biodiverse composition scenarios compared to the uniform composition scenarios. This supports the notion that climate-responsive designs incorporating biodiverse planting compositions are perceived as more effective in adapting Lausanne to climate change compared to designs that prioritize UGIs with limited biodiversity.

The results also indicate that increasing tree coverage is perceived by respondents as a more favorable climate change adaptation strategy compared to making the soil more permeable and biodiverse, as only two strong correlations can be observed between the canopy index and the PB and PAC scores for the biodiverse planting composition scenario ($r=0.509$ and $r=0.570$, respectively). It is noteworthy, however, that the strong correlation between PB and the canopy index for the biodiverse planting composition scenario might appear counterintuitive, considering that the additional species in the photomontages primarily belong to the herbaceous and shrub strata. Thus, the analysis of these correlation coefficients suggests that respondents place greater emphasis on the role of trees in adapting the city to climate change, potentially overlooking the contributions of soil-oriented planting compositions associated with the herbaceous and shrub strata.

It is important to acknowledge that these results are contingent upon specific urban contexts, which offer varying possibilities for soil renaturation and tree coverage expansion, as indicated by the previous analysis of average perception scores.

5 Discussion

5.1 Understanding and exploring the role of UGIs in adapting Lausanne to climate change

The application of our analytical framework provides valuable insights to discuss the role of UGIs in the adaptation of urban environments to climate change.

Firstly, the analysis reveals that perceptions are influenced by the clarity of the planting composition depicted in the photomontages. The significance of the results favoring public spaces with high PB and PAC scores is particularly pronounced for scenarios that exhibit physical attributes that play a prominent role in the comprehension of the environment. This is evident in the photomontages of S1 and S3, which demonstrate strong and easily comprehensible structures associated with their planting compositions. These scenarios are characterized by a few major units where the plant strata are organized along a main axis defined by tree and hedge alignments, providing a sense of order, directing attention, facilitating orientation, and aiding in the respondents' spatial perception. Furthermore, the presence of a greater number of trees in these scenarios is more readily perceived as a means of adapting cities to climate change. Conversely, attributes such as soil composition and the delineation of lawns, roads, and planted spaces contribute to respondents' overall understanding of the environment but may not be perceived as equally effective as trees in terms of climate change adaptation. Moreover, the results shed light on the influence of street openness and the proportions of public spaces on PB and PAC scores. The distribution of building proportions, including morphologies, volumes, and rights-of-way, as well as the size of public spaces, show close associations with the perceived scores. Additionally, the proportions of canopy coverage and the composition of the landscape also contribute to the legibility of the photomontages. Preferably, scenarios featuring large open spaces, such as those observed in S1, S3, and S5, tend to yield higher PB and PAC scores. In contrast, S4 and S6 represent enclosed sites, such as small squares surrounded by buildings or the inner areas of blocks bordered by residential and commercial buildings.

However, it is important to acknowledge the limitations of our study regarding the respondents' connection with the selected sites. A significant proportion of the respondents (approximately 74%) did not reside in Lausanne or even in the Canton of Vaud (12.7%), making it challenging to determine the extent of their familiarity with the chosen sites. The lack of personal experience with these spaces may have influenced the perception scores of PB and PAC, particularly for the peripheral and residential sites (S3, S4, and S5), which are potentially less familiar to respondents compared to more central and bustling sites (S1, S2, and S6).

Furthermore, all of the photomontages were crafted by professional landscape architects to create a realistic representation, aiming to enhance respondents' trust in the design and implementation potential of each site. However, it is worth noting that most of the photomontages depicted the sites during the summer season. This approach was adopted to enhance the visibility of IGUs' biodiversity and showcase the sites' capacity to adapt to climate change, considering the projected increase in temperatures and rainfall in Switzerland by 2050. On the other hand, the initial site photographs were taken during early spring, which presented a disadvantage compared to the biodiverse planting composition depicted in the photomontages. This discrepancy was particularly evident for sites that already possessed a significant level of IGUs (S3 and S5) in their initial state, as they were unable to demonstrate their full potential in terms of hosting biodiversity and adapting to climate change during the summer season. These limitations should be taken into account when interpreting the results of the study, as they may have influenced respondents' perceptions and the comparability between the initial and climate-responsive design scenarios. Future research could address these limitations by utilizing more comprehensive visual representations that encompass different seasons and time periods.

Table 3 Socio-demographic characteristics of the research population

Total		527	100%
Age	18–24	184	34.9%
	25–34	130	24.7%
	35–49	115	21.8%
	50–64	80	15.2%
	65+	18	3.4%
Gender	Male	187	35.5%
	Female	331	62.8%
	Other	9	1.7%
Geographical origin	Lausanne	191	36.2%
	Lausanne metropolitan area (Lausanne excluded)	108	20.5%
	Vaud Canton (Lausanne metropolitan area excluded)	161	30.6%
	Other Swiss Cantons	67	12.7%

Fourth, the UGIs depicted in the photomontages were designed to be visually engaging and diverse, providing a wide array of plants and natural elements that can be experienced by diverse individuals. This is particularly evident in the biodiverse planting composition scenarios, which introduce an additional stratum. The results indicate that the perception of a greater variety of visual elements and the richness of the photomontage correspond to a higher perceived potential for climate change adaptation. Respondents notably rated the species richness significantly higher for the S1, S2, S3, and S5 sites, which resulted in higher perception scores compared to other situations. Only S6 exhibited identical PB scores between the uniform and biodiverse scenarios, likely due to its street and open space conditions, as it is situated in the old city center and primarily consists of mineral surfaces.

Finally, the climate-responsive designs depicted in the photomontages were designed to be practical and facilitate easy exploration of the environment by diverse individuals. These designs were developed in collaboration with a landscape architecture firm experienced in similar projects, ensuring their feasibility. However, the feasibility guidelines also influenced respondents' perceptions of the role of IGUs in adapting the site to climate change. For instance, the composition of the S6 photomontage showcased minimal planting solutions due to its location in the historic center, taking into account feasibility and reliability considerations. Consequently, this may have resulted in lower PB and PAC scores for that particular site, regardless of the planting composition. Furthermore, to illustrate how the climate-responsive design facilitates easy exploration, most of the photomontages featured people who were absent in the

Table 4 Strength of the correlation based on the Pearson test *r*-value

<i>r</i> -value	Correlation strength
– 1.0 to – 0.5 or 1.0 to 0.5	Strong
– 0.5 to – 0.3 or 0.3 to 0.5	Moderate
– 0.3 to – 0.1 or 0.1 to 0.3	Weak
– 0.1 to 0.1	Non-existent or very weak

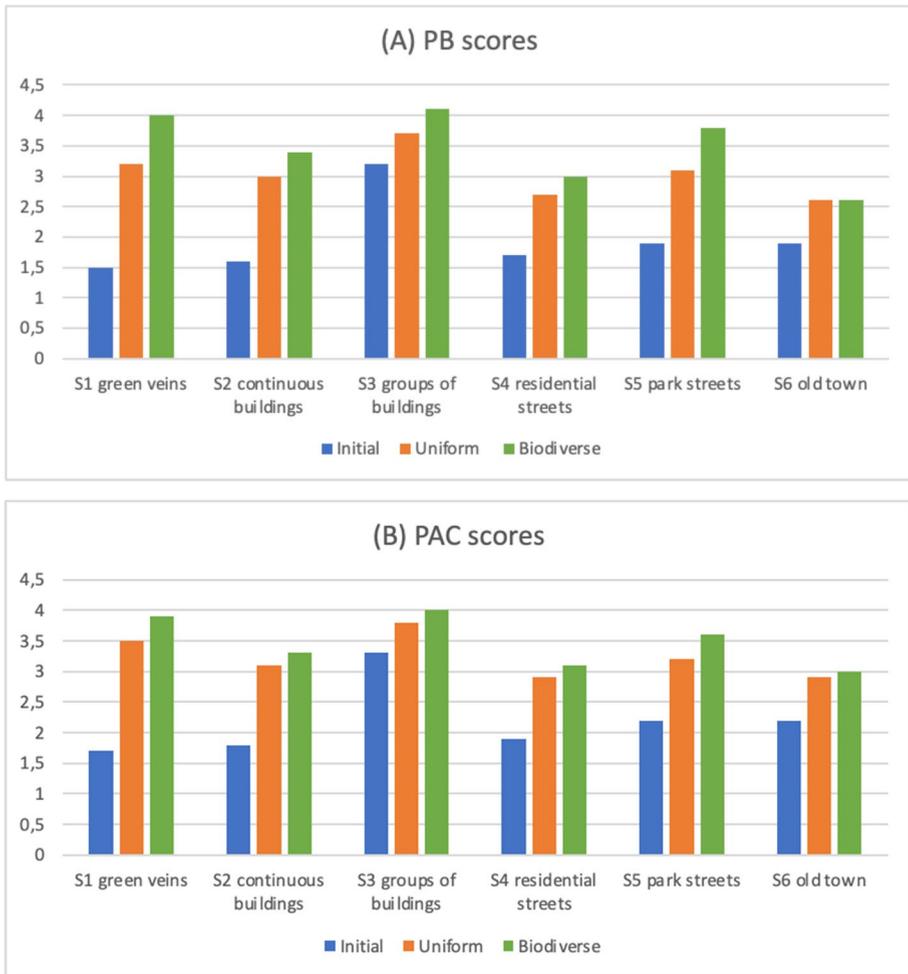


Fig. 5 Average PB (A) and PAC (B) scores obtained for each site

initial site condition photographs. This absence of people in the initial site pictures might have further contributed to the disparities between the initial site and climate-responsive design PB and PAC scores.

Table 5 Results of the Pearson test

	Uniform	Biodiverse
Canopy coverage	PAC 0.437	PAC 0.509
	PB 0.457	PB 0.570
Soil permeability	PAC 0.358	PAC 0.396
	PB 0.412	PB 0.459

5.2 From climate-responsive design to more sensitive approaches to adapt cities to climate change

The perception scores obtained through the photomontages also allow for a discussion about visuals and aesthetics. According to Carlson and Berleant (2004), aesthetics refers to the conditions under which an environment can exist and be appreciated by individuals. The aesthetic character of a place is not solely determined by psychological factors or the inherent beauty of the place itself. It emerges from culturally-defined uses, including language and practices, as well as affective appreciation of the place (Ulrich 1983). The relationship between communities and natural elements is not solely based on “objective” and measurable qualities; it is influenced by various parameters, such as individual perceptions, representations, experiences, cultural belonging, values, expectations, and sensitivities.

The survey results shed light on the significance of culture and expectations in shaping the perception of UGIs’ role in adapting Lausanne to climate change. Pearson’s tests highlight the prominence of trees in collective representations regarding climate change adaptation in the city, overshadowing the importance of soil permeability and renaturation strategies. This raises the question of how cultural factors and sensitivities play a role in reconsidering specific natural elements for climate change adaptation, particularly at the ground level for the herbaceous and shrub strata.

Hence, we propose that climate-responsive design should prioritize sensitivity, aligning with Brady’s (2014) call for action. Sensitivity emerges as a crucial concept for developing adaptive strategies that embrace renaturation principles. These strategies should not only be responsive to current climate disturbances but also demonstrate sensitivity towards nature (including water, air, wind, soil, fauna, and flora) and the cultural and aesthetic preferences of communities. By incorporating sensitivity from the early stages of climate-responsive designs, a deeper understanding of the co-benefits of biodiversity can be fostered among a broader audience. Designers and communities can transcend the conventional perception of trees as the sole symbol of environmental benefits and embrace a holistic approach that recognizes the capacity of planting compositions to adapt the environment and align with cultural design practices.

6 Conclusion

Our research demonstrates that individuals, particularly residents of Switzerland, recognize the development of UGIs as a means to adapt cities to climate change. Specifically, residents acknowledged that biodiverse planting compositions played a significant role in climate adaptation in Lausanne. However, the emphasis on trees over the herbaceous and shrub strata in addressing climate change issues was notable, despite the majority of depicted biodiversity belonging to these lower strata. Additionally, it is essential to consider the contextual constraints of urban environments, as more enclosed and impervious areas were perceived as less effective for climate change adaptation, regardless of the planting composition.

This study also contributes to a deeper understanding of the dynamics of perception associated with the development of public spaces, providing insights for public policies to capitalize on these perceptions. By strategically mobilizing various visual representations,

both public and private stakeholders can promote the role of biodiversity in enhancing climate change adaptation and secure public engagement in climate-sensitive designs.

Future research could expand the geographical scope to examine regions with different climatic constraints, public spaces, streetscapes, and cultural traditions to envision more sensitive ways to develop climate-responsive design.

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Author contribution Claire Doussard: conceptualization, methodology; formal analysis and investigation, writing—original draft preparation, writing—review and editing.

Muriel Delabarre: writing—original draft preparation, funding acquisition, resources.

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Data availability The datasets generated during and/or analyzed during the current study are not publicly available due to administrative and contractual clauses but are available from the corresponding author upon reasonable request.

Declarations

Competing interest The authors declare no competing interests.

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