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The Potential Health Benefits of Urban Tree Planting Suggested through Immersive Environments

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Abstract: Disruptive change in urban landscapes, such as large-scale tree planting, is complicated by the different priorities of the wide range of urban stakeholders. Here, we demonstrate an approach to the planning of urban green spaces using virtual reality simulations. We evaluate the health benefits (restorative benefits) and safety concerns of participants using virtual reconstructions of 10 urban parks in Bradford, UK, to simulate changes in woodland cover. Participants experienced each of the 10 parks as immersive environments with each of three scenarios: (i) no trees, (ii) real tree distribution, and (iii) doubling of tree numbers. Participants answered a short questionnaire while in each virtual park to quantify their feelings of safety and the restorative benefit that they thought they would experience. The results show that our VR approach produces reported restorative benefits that are not significantly different from those reported in the physical parks during visits by participants. We then demonstrate that increased tree cover is associated with significant increases in perceived restorative benefit, with some evidence of saturation at higher tree densities. Reductions in tree cover lead to a reduction in reported restorative benefit. We suggest that immersive technologies present a useful tool for the consultation and co-design of urban landscapes.

Keywords: virtual reality; biodiversity; tree; urban landscape; attitudes; park; perceptions

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1. Introduction

A wide range of anthropogenic factors threaten the integrity of natural systems around the world, including climate change, invasive species, pollution, and land use change [1]. Concurrently, there has been a growing recognition of the value of these natural systems in supporting a range of human activities, referred to as "ecosystem services" [2]. These two processes lead to a paradox in which humans rely on the landscapes that they are degrading, necessitating careful land management to ensure the sustainable use of natural resources. Such management decisions aim to create mutually beneficial scenarios that improve the functioning of natural systems while maintaining their utility for humans (so-called "win-win scenarios"). Sustainable management of landscapes is particularly complex in urban areas, where space is predominantly used for human activities, intensifying the complexity of these decisions [3].

In the UK, over 80% of the national population lives in cities, but the social, educational, and health benefits of urban living are traded off against the concomitant degradation of the urban landscape [4]. Large aggregations of people can cause a heavy environmental burden [5]. The poor air quality seen in many of the world's cities is of particular concern due the ever-increasing traffic, industrialization, and energy consumption; this is thought to pose a widespread threat to public health [6]. A high occurrence of stress-related disorders and depression has been noted in modern cities, highlighting a need for their mitigation. This has given rise to a new interdisciplinary field of research termed "neurourbanism", which looks at urbanization and mental well-being with the goal of supplying health and planning bodies with the necessary knowledge to meet these challenges [7]. Studies have shown that the risk of developing serious mental illness is generally higher in cities compared to rural areas due to a combination of these physical and social factors [8,9].

Studies on the impacts of cities on biodiversity have concluded that urban ecosystems usually act to reduce biodiversity and homogenize biological communities [10,11]. Meanwhile, links between health and biodiversity suggest that a greater number of species is associated with increased health outcomes [12,13]. It has been reported that more regular access to urban green spaces improves mental health and well-being for people of all ages regardless of the cultural and climatic context [14]. The route through which this is thought to occur involves the role of green spaces in promoting social cohesion, the provision of space to support physical activity, the capacity to reduce exposure to air and noise pollution, and the potential to alleviate stress [15]. Areas with a higher amount of urban green space have been shown to be more effective at alleviating psychophysical stress, which has been measured through their greater ability to decrease cortisol levels [16], and it has been suggested that even short-term visits to urban green spaces aid in stress alleviation [17]. Urban green spaces can therefore be considered as "restorative environments" due their ability to support the renewal of cognitive resources which have been depleted by the demands of everyday life [18]. The "restorative benefit" is an important health benefit provided by an urban green space that is linked with its ecological quality. Ecological quality is linked with greater species richness and biodiversity, and it is believed that urban green spaces with higher perceived species richness and biodiversity have a greater restorative benefit [12,19,20]. Green space enhancement and extension has been recommended as a key tool for enhancing human health in urban landscapes [21], but these recommendations are being made against a backdrop of reduced funding for urban green spaces [22] and a relatively weak evidence base for the mechanisms of benefit [23].

The weak evidence for links between green spaces and human benefit is a challenge for policymakers and practitioners. For instance, up to 15 out of 17 Sustainability Development Goals (SDGs) can be addressed using urban green spaces for urban issues, but research into those solutions has been limited to a small number of areas [24]. The multiple dimensions of the SDGs provide a useful framework within which to plan urban enhancements to achieve a range of benefits, using green spaces as "spaces of opportunity" in cities [25]. Those opportunities have been operationalized into frameworks for urban greening, for example, as part of the European Union's Biodiversity Strategy for 2030 [26]. However, implementation of that strategy may be compromised by insufficient engagement with society and challenges associated with higher public participation [27]. To enhance community engagement and co-design, large-scale pilots of citizen engagement around biodiversity in cities are underway in a variety of locations [28].

Despite the recognition of the need to consider social drivers of and barriers to environmental change, there are few methods that bring together the natural and social realms so that the two can be studied together. Fieldwork has been the core method used, where human participants are approached and asked about their experiences or perceptions of the natural world [12]. Other approaches have used creative means to explore attitudes toward more abstract concepts of nature [29], while further studies have either presented photographs to explore attitudes to specific landscape changes [30] or asked participants themselves to take photographs of landscape features to explore attitudes more generally [31]. However, such methods are limited by the availability of sites that can be used as stimuli for specific experiments (either in situ or ex situ). Here, we describe a flexible approach that can be used to simulate detailed, realistic scenarios of potential changes in real-world landscapes such that participants can experience and respond to changes in a more realistic manner.

To explore the use of virtual environments for environmental psychology and urban design, we manipulated the number of trees present in a series of simulated urban parks. Increasing the species richness of static components of biodiversity (e.g., trees, flowers) was found by Fuller et al. [12] to be the aspect of biodiversity which was most accurately assessed by participants in their experiment. Tree cover was also found by Dallimer et al. [20] to be a proxy for increasing "perceived" species richness and biodiversity. Tree planting has also risen in prominence as a local solution to climate net zero goals, and, thus, is a highly relevant intervention to evaluate within an urban setting. We use this virtual framework to evaluate two important hypotheses:

Hypothesis 1. *Real parks and their virtually recreated versions have a correlated restorative benefit. Firstly, we evaluate whether a virtual simulation of an urban green space can elicit similar responses to physically being in the green space. We compare the restorative benefit results obtained from the real parks in a previous study* [32] *to the same parks having been recreated in virtual reality. Support for this hypothesis would unlock the use of virtual environments for environmental psychological research.*

Hypothesis 2. *Increasing tree cover in virtual reality urban green spaces increases their perceived restorative benefit to visitors. Secondly, we manipulated 10 urban parks within virtual reality to either remove all trees or double the number of trees. Participants were exposed to the zero trees, real trees, or double trees variants of each park and asked to rate their perceived restorative benefits. Support for this hypothesis would provide important experimental confirmation of previous observational studies* [12].

2. Methodology

Bradford is a city of ca. 540,000 people living within a 64 km2 area situated in northern England [33] (Figure 1). We selected 10 Bradford parks based on their use in a study of green space biodiversity and human well-being [32] (Figure 1). The parks varied in their configuration, biodiversity, and tree cover. Unity3D 2018.2.0f2 (Unity Technologies) game design software was used to produce virtual simulations of the parks based on a combination of aerial photographs, digital maps, and site visits. All the experiments were run on an HTC Vive in a space of approximately 3m x 3m, on a computer equipped with a Nvidia GTX 1070 graphics card and an Intel CPU. The main priority of the digitization was to accurately map the topography, land cover types (paths, grass, trees), and the locations of large, prominent objects such as playgrounds and shelters as close to those of the real-life parks as possible (Figure 2). There are both "high-level" and "low-level" parameters when it comes to building the geometric models for virtual environments. High-level parameters include numbers and types of objects, weather, etc., while low-level parameters involve appearances such as textures, lighting, number of triangles, etc., that influence the complexity of the environment. Due to the experiment using VR, the performance of the environments (the user experience) was an important consideration. Each park environment was designed to achieve more than 90 frames per second for fluid VR. Replicating the parks exactly is extremely difficult, especially when we need to minimize the impact of peripheral factors by keeping them the same. Finally, we used the same lighting and the same set of objects (replicated based on specific scenarios), including geometry and texture.

The 10 parks were created to simulate the structures and sizes of their real counterparts, including the observed distribution of trees ("true trees"). Two further variants were then created of each of these 10 original parks. In one of the variants, all the trees were removed from the parks ("no tree" parks). In the other variant, the tree coverage was doubled ("double tree" parks, see Figure 2). In simulating the doubling of tree numbers, our aim was to increase the tree cover in a way that might match how land managers would add trees in the landscape. To achieve this pattern, we first explored the current strategy for planting (spaced out individual trees; the presence of small, dense woodlands or tree-lined paths) and then expanded those planting patterns. Figure 2 shows schematics and aerial imagery of three example parks with different planting approaches. Emsley (142 trees present in reality) contains a block of trees in a wedge-like area of woodland in the north of the park and a thinner band of trees lining the western side of the park. In adding trees to Emsley, we added two further blocks of trees in the eastern and southeastern areas of the park, and added trees lining the eastern side of the park to resemble the western edge. In Castle Street (53 trees in reality), trees are generally located around the edge of the park, with some small clusters of 3–4 trees. We added trees to thicken and complete these existing lines of trees around the park edges. In Trident (82 trees in reality), trees line the outside of the park, following the paths through the park, and there are small, low-density clusters of trees in the south. We added additional trees to line the paths in other parts of the park to increase the density of the trees lining the park, and to create additional small clusters. Figure 3 shows the first-person view of the virtual parks. To ensure consistency, we used the same set of assets in Unity, which included trees, benches, bushes, and other typical park features. Assets were taken from Unity's standard assets and other packs freely available on the asset store. The user was positioned initially at the center, then given the options to either walk or teleport. Simple interactions such as moving objects (e.g., tree leaves rotating to simulate wind) were also provided to enhance immersion.

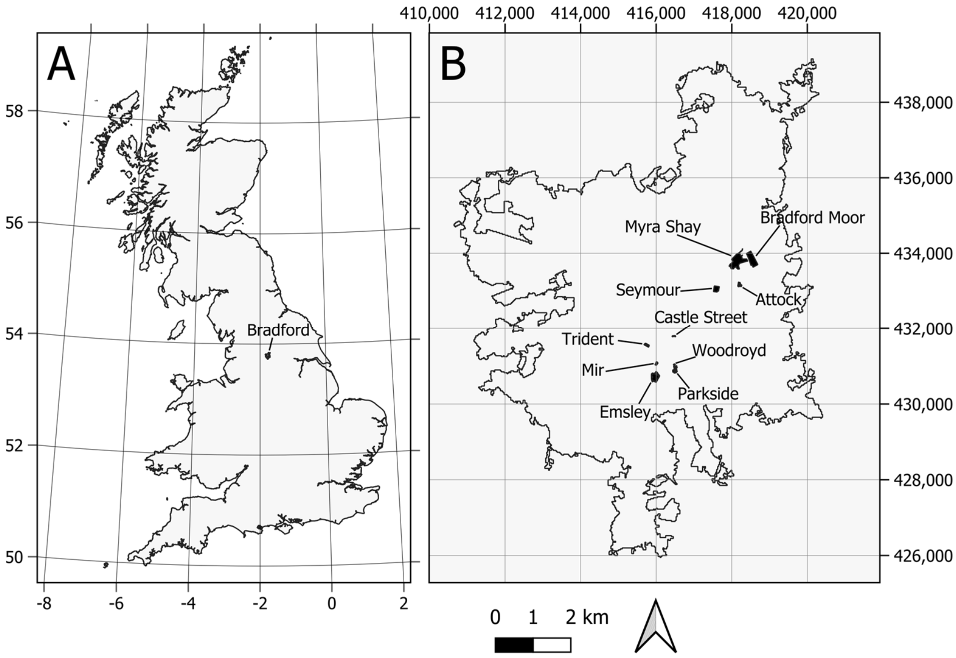

Figure 1. Map showing (**A**) the location of the city of Bradford within the UK and (**B**) the locations of 10 parks (shown in black) within the city.

The data for the study were collected in two studies corresponding to the two hypotheses above. All participants were students at the University of Leeds. Since the aim of the study was a methodological proof of concept around the use of VR in urban planning, we did not collect demographic information about the participants. However, our participant group was representative of the wider student cohort at Leeds: 91% of students were <24 years old, the majority (ca. 57%) were female, and the majority (72%) were of White British ethnicity [34]. In **Study 1** (testing hypothesis 1), we recruited 10 participants who each viewed 7 virtual parks with the real number of trees. Participants were placed within the virtual environment and given time to acclimatize to ensure comfort within the hardware. The seven parks were selected because they had also been visited physically by participants in a previous study [32]. No tree manipulations were used in the first study, as the aim was simply to cross-validate the responses from participants to the virtual and physical parks. To explore variation in perceptions among parks, we used a reduced version of the Likert scale statements used by Nordh et al. [35] in their photo-elicitation study about pocket parks in Scandinavian cities, based on the Attention Restoration Theory (ART) of Kaplan and Kaplan [36] and the 21-point ART questions developed by Hartig et al. [37].

These statements were: (i) there is a lot to explore and discover here; (ii) this place is a refuge from unwanted distractions; (iii) I would be able to rest and recover here; (iv) I like this environment; and (v) I feel safe in this park. For each question, participants were asked to respond verbally on a five-point Likert scale: strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree. Participants were also asked for the reasons for their response. The same restorative benefit survey had been used by Wood et al. [32] with human participants in the same parks, allowing for a direct comparison between the Wood et al. field sites and the present study's virtual environments. **Study 2** (testing hypothesis 2) involved the use of all three variations (no tree, original, double tree) of each of the 10 parks. Study 2 was conducted in two parts. First, a group of 10 participants rated each of the tree variations of 3 parks as a pilot study. The aim of the pilot was to collect preliminary data and to evaluate the comfort and immersion of the participants. When that pilot study was successful, we recruited a second group of 21 participants who viewed 10 randomly selected variations of the 21 variations of the remaining 7 parks. Between the two parts of Study 2, each park variation received 10 visits.

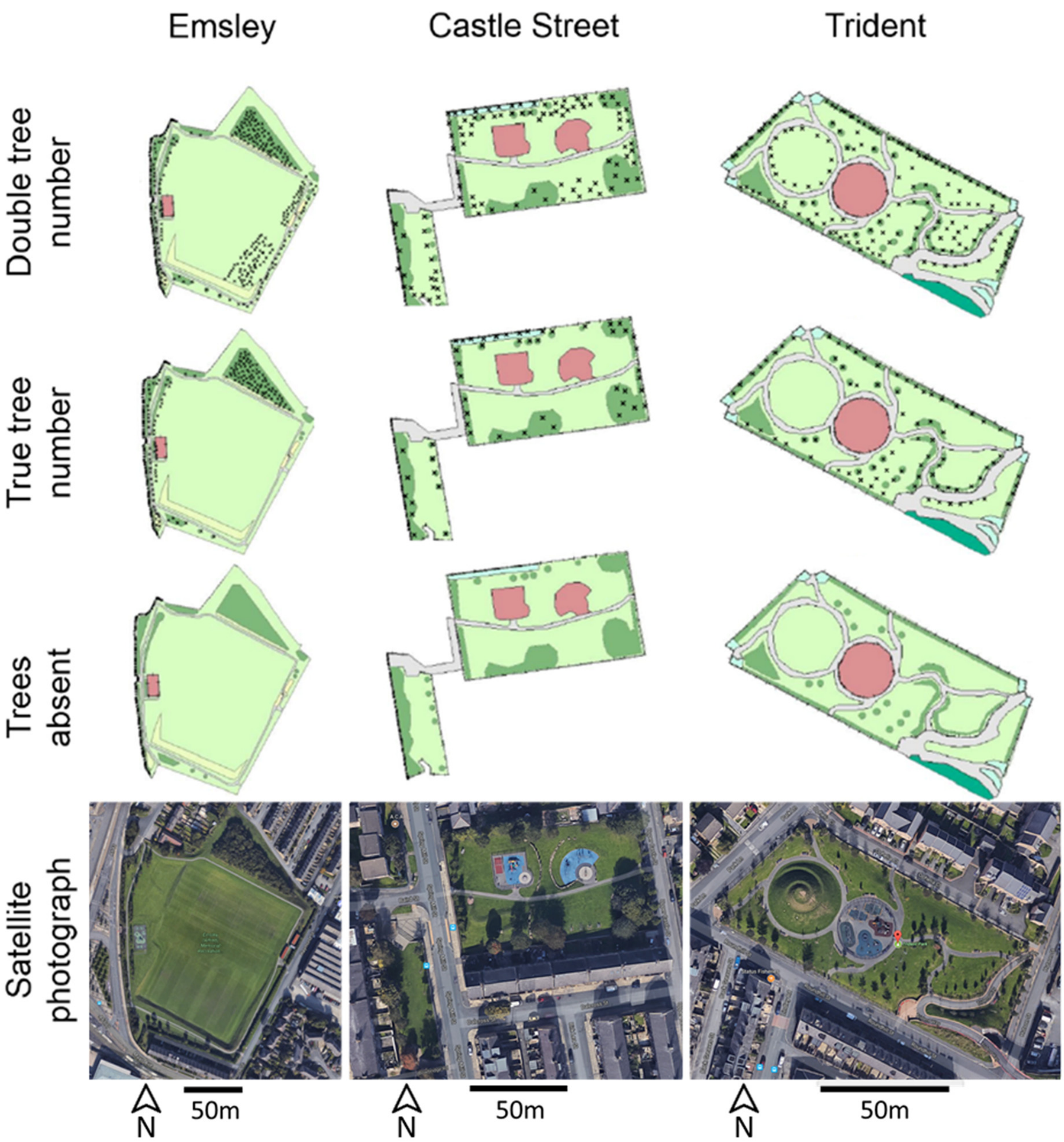

Figure 2. Three parks in Bradford, UK. The bottom row shows satellite images of the parks. Other rows show simplified schematics of the park layout on which tree locations are marked with small crosses to illustrate the absent trees, true tree, and double tree treatments.

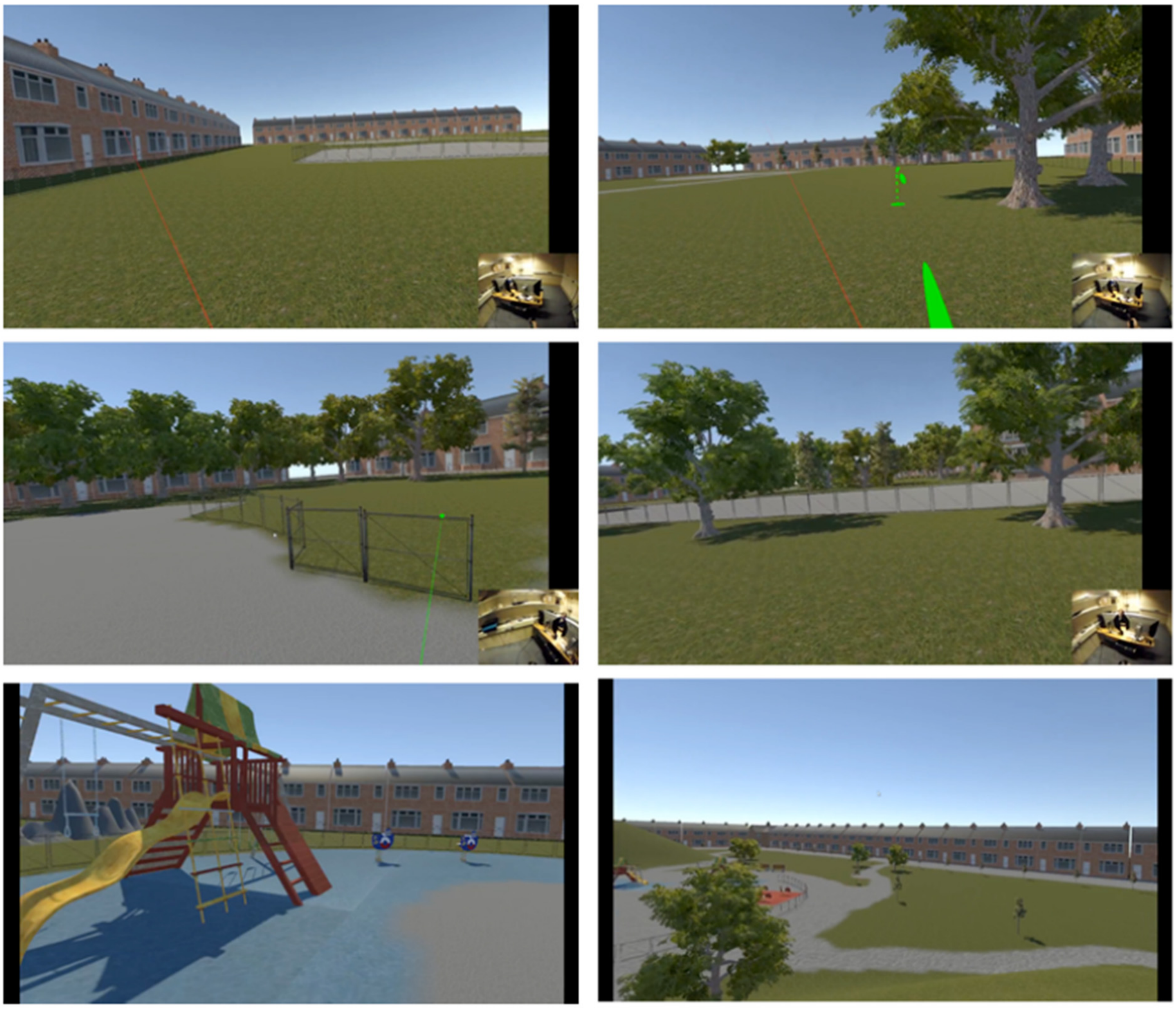

Figure 3. First-person views of the virtual parks. The green curve is the teleportation tool. Parks were gradually populated with more objects to create rich environments. The top row shows the simplest scenarios during the creation of the parks, the middle row shows key assets (fences, trees), and the bottom row shows the fully populated scene at Trident Park.

3. Statistical Analysis

To test the first hypothesis, we tested for agreement in restorative benefit scores between visits to the real-world parks reported by Wood et al. [32] and those from our virtual simulations of the same parks. We used a Pearson correlation on the mean restorative benefit scores (the average of the Likert responses from the five questions) from the seven parks that overlapped across the two datasets to quantify the correlation between the two sets of stimuli (i.e., did the virtual and real parks yield quantitatively similar scores?). We then used a paired t-test to test for a consistent difference in the scores (i.e., are virtual or real parks consistently rated more highly?).

To test the second hypothesis that tree cover influences reported restorative benefits, we analyzed the mean restorative benefit scores using generalized linear mixed effects models (GLMMs) in the lme4 package [38] in R. Models used the average Likert scale score across the five questions for each participant as the response variable, with tree treatment as a fixed effect and park and participant ID as random effects. Having participant as a random effect allowed us to account for the slight differences in design between the two parts of Study 2. The study design was approved following ethical scrutiny by the University of Leeds Faculty of Biological Sciences Research Ethics Committee (LTSBIO-014).

4. Results

Participants responded positively to the virtual environments and quickly grasped the teleportation and walking aspects of the controls, which were the same in both Study 1 and Study 2. They were observed attempting to interact physically with the virtual objects, particularly tree branches and fences. Informal feedback from the participants suggested that they found the environment user-friendly and engaging. For the statistical analysis below, we used an alpha level of 0.05 to determine significance for all tests.

Hypothesis 1: Real parks and their virtually recreated versions have a correlated restorative benefit. A comparison of the overall mean restorative benefit of the virtual reality parks with the overall restorative benefit of the real parks showed a strong but non-significant correlation ($R = 0.598$, $p = 0.156$; Figure 4). A paired *t*-test showed that there was not a statistically significant difference between the overall restorative benefit values obtained ($df = 6$, $t = 0.746$, $p = 0.484$). Taken together, these findings suggest that the virtual reality parks and the real parks do not have consistently smaller or larger restorative benefits when compared with each other. However, qualitative data showed that there were differences in the salient features on which those responses were based. Table 1 shows the most frequent reasons participants gave for their respective restorative benefit scores across all parks from the virtual reality parks in this study and the real parks in the Wood et al. [32] study. While openness and trees were both important in determining responses to the parks, people visiting real parks were more likely to notice cleanliness, biodiversity, and the wider spatial context—all of which represent details that were not included in the virtual simulation.

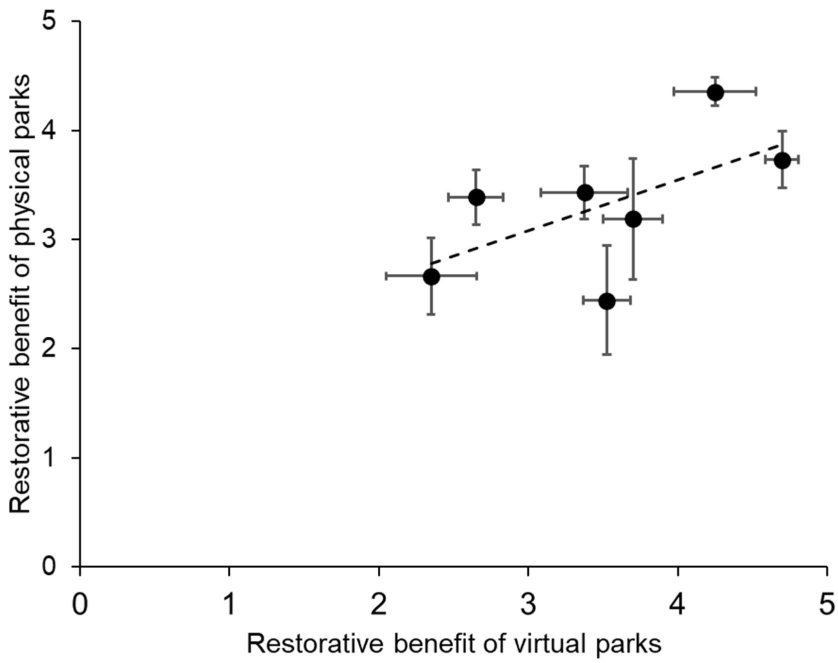

Figure 4. Comparison of the restorative benefits reported by visitors to real parks (*y*-axis, from Wood et al. [32]) and participants in virtual reality visiting simulations of the same seven parks. Error bars = 1SE, dotted line shows best-fit regression line.

Hypothesis 2: Increasing tree cover in the virtual reality urban green spaces increases their perceived restorative benefit to visitors. There was a significant positive effect of trees on restorative benefit, with increased in benefit when more trees were present ($t = 19.587$, $p < 0.001$; Figure 5). The GLMM had a conditional R^2 (explanatory power of both random effects due to participant and park, and the fixed effects of the tree treatment) of 0.786 and a marginal R^2 (tree treatment only) of 0.377. Thus, our models explain a large proportion of the variance in the restorative benefit, and even accounting for diverse park designs, the tree effect in isolation was substantial at close to 40% of the explained variance. This effect manifested as a decline in restorative benefit when trees were removed (zero trees) and an increase in benefit when trees were added (double trees) relative to the real tree numbers observed in the parks. However, it is worth noting that the differences between the tree treatments varied among the parks. For example, a doubling of tree numbers produced relatively minor increases in reported restorative benefit in Castle Street, while doubling trees produced a significant increase in restorative benefit in Trident and Emsley (Figure 5). These differences may represent a saturation of the benefit at higher levels of starting tree cover.

Table 1. The most frequent reasons for participants giving their restorative benefit scores.

Virtual Reality		**Real Parks [32]**	
Positives	**Negatives**	**Positives**	**Negatives**
Openness Trees Playgrounds Water features Seated areas	Sports courts/pitches	Openness Clean Trees Greenery Wildlife Playgrounds	Antisocial behavior Litter Dog excrement Vandalism Surrounding area unpleasant

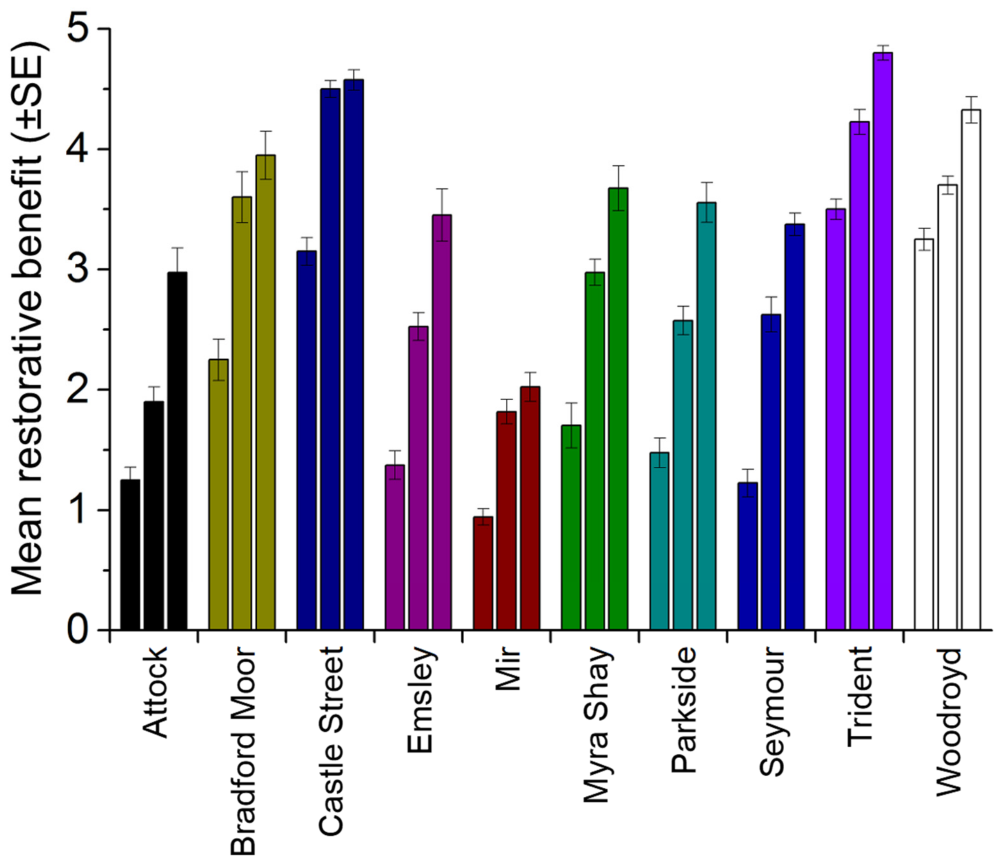

Figure 5. Mean restorative benefit across all participants (n = 10) reported for each park and each tree treatment (left = no trees present, center = the real tree number present, right = double the real number of trees present within the virtual landscape). Each bar is an average of the ratings from 9–11 different participants.

5. Discussion

We present a VR-based method to evaluate the attitudes and perceptions of users of urban green spaces. We demonstrate two key findings that support the use of virtual reality in urban green space design and research. Firstly, we demonstrate that physical park visits and virtual park visits elicit similar reports of restorative benefits from participants. Secondly, we provide experimental evidence supporting the observations of previous work that highlighted a role of changing tree cover as a potential driver of perceived health benefits (measured as self-reported restorative benefit) in green spaces. VR may provide a cost-effective tool with which to explore such questions, and below, we discuss the implications of these findings.

A range of approaches has been taken to studying human perceptions of urban green spaces. Observational studies have focused on studying participant reactions to a diversity of real-world green spaces, necessitating large sample sizes and comprehensive analyses to explore causal factors [12,20]. Quasi-experimental approaches have selected sites that represent variations in a given parameter of green space to use as stimuli [39]. Other studies have physically created a diversity of different green space configurations, for example, by planting different wildflower mixes to manipulate the appearance of botanical communities [40]. Recent studies have used 360-degree photospheres manipulated to act as stimuli for environmental psychology studies [41]. The immersive virtual reality environments that we demonstrate in this study have both advantages and disadvantages compared to other methods. Importantly, we demonstrated that our VR approach yields similar findings to visiting real spaces, whereas cross-validation of methods is rarely attempted in other methods. Manipulation of environments is quick and simple, and produces experimental stimuli that allow for complex experimental designs. However, it is also clear that our simulated parks lacked many of the details on which participants might have based judgements, including evidence of antisocial behavior (litter, dog feces, graffiti) or an ability to evaluate the surrounding area. The relative importance of those factors requires attention if these methods are to become more commonplace.

The empirical approach that the VR environments facilitate also allowed us to generate novel experimental insights into the drivers of variation in perceived psychological restoration. We demonstrate that parks with a greater number of trees generally have a higher restorative benefit value. Significantly, we can demonstrate this effect while holding all other aspects of the park the same, attempting to study the effect in parks that may vary in tree cover, but that also have many other confounding differences. However, as is the case in previous studies, we cannot tell for certain whether participants experienced improvements in perceived restoration directly as a result of the increase in tree numbers or whether participants were using tree numbers as a proxy for "perceived" biodiversity [20]. Regardless of the mechanism, the pattern is consistent with previous literature which demonstrated that tree cover is positively associated with the restorative benefits of real parks [12,20,42].

Our study also has considerable promise for the assessment and quantification of cultural ecosystem services (aesthetic and psychological) provided by urban green spaces. Quantifying these processes within urban green space design is important as it can improve our understanding of ecosystem services and disservices and can allow us to analyze the costs and benefits to help resolve trade-offs [43]. Correct quantification of ecosystem services can greatly aid in the decision-making process related to land use and management [44]. Urban green space development projects need to consider the provision of other ecosystem services to be effective. While win-win solutions may be the aim of many projects, such multifunctional solutions are difficult to achieve in the absence of careful design. Combining both an awareness of what situations may produce a trade-off with an understanding of why (and what) trade-offs result provides a much better chance of creating win-win solutions [45]. Our study has shown that it is possible to enhance regulating ecosystem services through tree planting (biodiversity, carbon storage, urban heat island mitigation, water retention) while also enhancing cultural ecosystem services (psychological restoration), with no evidence of disservices associated with reduced safety.

The immersive realities approach may enable more studies to explore potential trade-offs at an early stage of design and, in so doing, become an important part of the planning phase of urban green space developments. Such innovations are crucial when addressing issues with the implementation of large-scale policy strategies [27], and can be incorporated in a highly flexible way into exploratory frameworks for citizen involvement with urban landscape management [28]. Already there have been applications of VR within a co-design context to engage local communities and help to visualize plans for urban design [46]. As a standard part of public engagement during the formal consultation around large-scale change in cities, such technologies have the exciting potential to not only visualize proposed futures, but also to explore potential futures in areas that currently lack green spaces. Such an approach could open up opportunities to resolve inequalities ("green gaps") in urban areas by raising awareness of what is possible in green space design [47]. Further applications have been explored that augment the view of the city to reveal infrastructure and systems that are concealed below ground, but vital to urban functions [48]. Such complexities highlight the scarcity of land in cities and, as a result, that decisions on urban infrastructure development are unlikely to be made by one "actor" due to the complexities involved within such a densely packed social system. Instead, multi-actor adaptive decision making (MAADM) approaches are needed to ensure that different actors work together effectively and produce the best strategy in urban development [49,50]. At a time when urban trees (particularly in the UK) are the focus of significant conflict between local governments, citizens, and contractors [51,52], there is a clear need to improve collaboration and communication between actors. Urban green space planning requires the communication and collaboration of government and community groups, and strategies must also involve collaboration between urban planners and ecologists to maximize public benefits and the environmental quality of any developments [53].

6. Conclusions

The management of urban landscapes requires rapid action to address multiple challenges faced by society, including biodiversity decline, climate change, and human health. Addressing those challenges requires solutions that have multiple benefits and that are acceptable to local residents. We have demonstrated that immersive realities can be used to elicit perceived health (restorative) benefits from people that resemble field data. Furthermore, we show that manipulations of immersive environments can produce shifts in perceived benefits that match what would be predicted based on field studies. Our work raises key questions for future research. Firstly, what are the optimal levels of realism required to simulate real-world locations adequately for use in studies that explore urban green space design? Secondly, can immersive realities function as exploratory spaces to break down barriers to urban landscape change that are rooted in conflict between different stakeholders with different priorities? Thirdly, how can virtual environments be used to create urban futures through awareness raising and co-design of innovative and radical solutions to urban challenges?

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land13030290/s1, File S1.

Author Contributions: Conceptualization, C.H. and H.W.; methodology, H.W., M.N. and C.H.; software, H.W., M.N. and E.N.; formal analysis, C.H. and E.N.; investigation, M.N., E.N. and H.W.; data curation, M.N. and E.N.; writing—original draft preparation, C.H., E.N. and M.N.; writing—review and editing, C.H., E.N., M.N. and H.W.; visualization, C.H.; supervision, C.H.; project administration, C.H.; funding acquisition, C.H. All authors have read and agreed to the published version of the manuscript.

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