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Users' Perceptions of the Contribution of a University Green Roof to Sustainable Development

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Abstract: Universities are well placed to adopt and use the UN Sustainable Development Goals (SDGs) on their campuses to educate and showcase how the SDGs can be delivered in the built environment. Green infrastructure, such as green roofs, green walls, or green parks, are highly visual implementations with environmental and social benefits that contribute to several SDGs, such as 3 (good health and wellbeing), 10 (reduced inequalities), 11 (sustainable cities and communities), 13 (climate action) and 15 (life on land). These features may be referenced in sustainability teaching and learning, which may raise and heighten awareness of the social, economic, and environmental benefits of green infrastructure. In this study, we explored users' perceptions of the extent to which a university campus green roof contributes to the SDGs and whether users focussed more on its social or environmental benefits. Statistical analyses, namely independent samples *t*-tests and analysis of variance, were conducted to determine what influenced users' perceptions of the green roof. The analyses revealed that users' perceptions did not differ largely by sociodemographic characteristics, though students perceived the social benefits as greater than university staff. Those with greater knowledge of green roofs perceived its environmental benefits as greater, but not the social benefits. The findings demonstrate the importance of green infrastructure on university campuses for encouraging engagement with the SDGs, whilst indicating that knowledge of such infrastructure increases appreciation of their environmental credentials.

Keywords: green infrastructure; green roofs; user perceptions; sustainable development goals; environmental benefits; social benefits

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1. Introduction

Sustainable development is the idea that human advancement and progression should occur in a manner that benefits the environment, economy, and society simultaneously, with intra- and intergenerational equity likewise contributed to and maintained [1]. The United Nations Sustainable Development Goals (SDGs) are one manifestation of this approach, determining 17 targets in areas ranging from environmental to social to economic matters that humanity should aim to reach by 2030 in order to improve human health, equality, and combat climate change [2]. Universities are essential for addressing the SDGs—not only do they encourage and promote the education of students, particularly in topics relating to sustainability [3], but their campuses also offer sites to implement sustainable activities and infrastructure. In fact, many universities around the world have now made public commitments to address the SDGs, as promoted by the recent Impact Rankings released by Times Higher Education [4].

Green infrastructure within university campuses remains one common, and highly visible, form of sustainable implementation to address the SDGs. Green infrastructure, defined as infrastructure consisting of natural and semi-natural components with the primary intention of delivering ecosystem services, can take numerous forms [5]. For instance, green spaces, green roofs, and green walls have all been implemented within university contexts [6,7]. Green infrastructure has been observed to reduce energy and water use [8], minimise waste [8], protect biodiversity [6], and increase the social wellbeing and attachment to place of students [9]. These benefits align with several SDGs, including 3 (good health and wellbeing), 10 (reduced inequalities), 11 (sustainable cities and communities), 13 (climate action) and 15 (life on land).

Furthermore, the green infrastructure may also be referenced in teaching and learning about sustainability in many university courses offered in faculties and schools of Architecture, Science, Business, Health, and Engineering. Recent research has documented that the presence of green infrastructure advances the knowledge and education of environmental and social sustainability for those who interact with and use the infrastructure [10–12], including among university students [13]. Green initiatives within university campuses have also been found to contribute to students' knowledge of sustainable development itself [8]. Ensuring widespread knowledge of sustainable development is critical for encouraging future action, educating and raising awareness about climate change and sustainability, and promoting pro-environmental attitudes [8]. Thus, green infrastructure could provide a pivotal means for universities to encourage the tackling of sustainable development beyond their campuses.

Similarly, understanding people's perceptions of how particular forms or types of green infrastructure contribute to addressing sustainability challenges and meeting various SDGs is important for decisionmakers looking to justify the inclusion of such infrastructure [12]. Positive perceptions of the sustainability impacts of green initiatives indicate that the infrastructure is functioning as desired and is having beneficial effects on the surrounding local community, including improving wellbeing [14,15]. On the other hand, less positive or even negative perspectives of the green infrastructure and its impacts, could indicate that education and knowledge is not sufficiently present or that the infrastructure is not functioning as theorised or hoped [12]. Determining how people perceive the impacts of green infrastructure can ensure it is having positive effects, such as those to education and knowledge that was outlined previously.

Yet, research exploring how people perceive green infrastructure's contribution to the SDGs is still in its infancy and warrants closer attention [12], particularly on university campuses and for students. There is room to explore how particular forms or types of green infrastructure, such as green spaces and green roofs, may shape users' perceptions of their environmental and social impacts [16]. Consequently, in this cross-sectional study, we seek to explore users' perceptions of the extent to which a green roof on a university campus contributes to the SDGs. The few studies that have explored perceptions of green infrastructures' contribution to the SDGs have tended to focus on urban green spaces [12,17], so there is a need to expand investigations to other forms of green infrastructure, such as green roofs, and to test whether similar results are obtained.

2. Theoretical Framework

Conceptually, individuals' perceptions of green infrastructure are often theorised to be influenced by intrapersonal factors, such as values, beliefs and knowledge, sociodemographic characteristics, including age, gender, and education, and environmental conditions, such as the type of green infrastructure [15,16]. In order to understand perceptions of particular types of green infrastructure, such as green roofs, it is necessary to consider the role these different categories may play.

Individuals' values, beliefs and knowledge play an integral role in determining their perceptions of green infrastructure and its contribution to sustainability. For instance, the set of values and beliefs an individual holds, towards society, the planet, and nature itself, shape

how they perceive both sustainability action [18] and the role of green infrastructure in contributing to such action [8]. Likewise, previous research exploring knowledge and perceptions of sustainable drainage systems, as a form of blue green infrastructure, has found that those who have greater knowledge and awareness of the drainage system perceive its environmental benefits as more significant and beneficial [15,19]. Knowledge of green roofs also has been found to correlate with more positive perspectives [20]. It is important to mention, however, that this relationship is not necessarily one directional—universities and green infrastructure have also been observed to be critical influencers of knowledge of sustainability [10,21]. Thus, the relationship between perceptions and knowledge is likely co-constitutional and complex. It is essential that knowledge of the role of green infrastructure on university campuses is well disseminated so individuals can accurately perceive their impacts.

An individual's sociodemographic characteristics which also determine the extent to which they perceive green infrastructure may contribute to the SDGs. For instance, females, younger people, and those with more years of education have been observed to perceive the environmental and social impacts of green spaces as greater [12,17]. For universities particularly, students, as opposed to other users of university spaces, are also more likely to have stronger positive perceptions of the role of green roofs in contributing to sustainability [20]. As such, it is also necessary to consider sociodemographic characteristics when evaluating perceptions of green infrastructure and its contribution to the SDGs.

Finally, individuals perceive the social and environmental impacts of varying kinds of green infrastructure differently. This depends on the infrastructure's characteristics, how people interact with the infrastructure, and where or in what context it is located [16,22]. Users of green spaces have been observed to perceive the space's environmental and social impacts differently depending on its form and structure, such as whether it is a rooftop garden or green park [16]. Some of these differences result from the actual characteristics of the space such as its size, amount of greenery, visibility/accessibility and so on [14,15]. Likewise, the location of the green infrastructure, in regard to the distance the user must travel to interact with it, can also influence perceptions [12]. The context in which the infrastructure is located may also play a role: Jungels, Rakow, Allred and Skelly [20] observed that attitudes towards green roofs were more positive in garden contexts as opposed to universities, although the authors note that this could be for several reasons unrelated to context, such as the demographics of visitors.

In summary, we propose that an individual's perceptions of the sustainability contributions of green infrastructure are dependent on interpersonal factors, sociodemographic characteristics, and environmental conditions. Given that there has been little attention to whether this remains the case in university contexts and for green roofs, this study seeks to examine the perceptions of users of a university green roof, and to determine what influences these perceptions. Particularly, we focus on the role of knowledge of the green roof and sociodemographic characteristics in this relationship.

Research Questions

Consequently, the following research questions are posed to probe into the differences between users' perceptions of university green roofs and how they may contribute to the SDGs:

RQ1. Do green roof users' perceptions of the roof's contribution to the SDGs differ depending on their sociodemographic characteristics?

RQ2. Do those who have greater knowledge of the green roof perceive its social and environmental benefits as greater than those with less knowledge?

3. Materials and Methods

3.1. Context

The green roof explored in this study is located in the high-density inner-city campus of the University of Technology Sydney (UTS), in Sydney, Australia. The roof, known as the

Alumni Green, consists of a 1200 m^2 concrete open space containing a garden and grassed area (Figure 1). The roof is slightly above street level and stands over classrooms and the library's book retrieval system. As it is readily accessible by street, and the university campus is open to the public, the roof is used by both students, staff and those unrelated to the university.

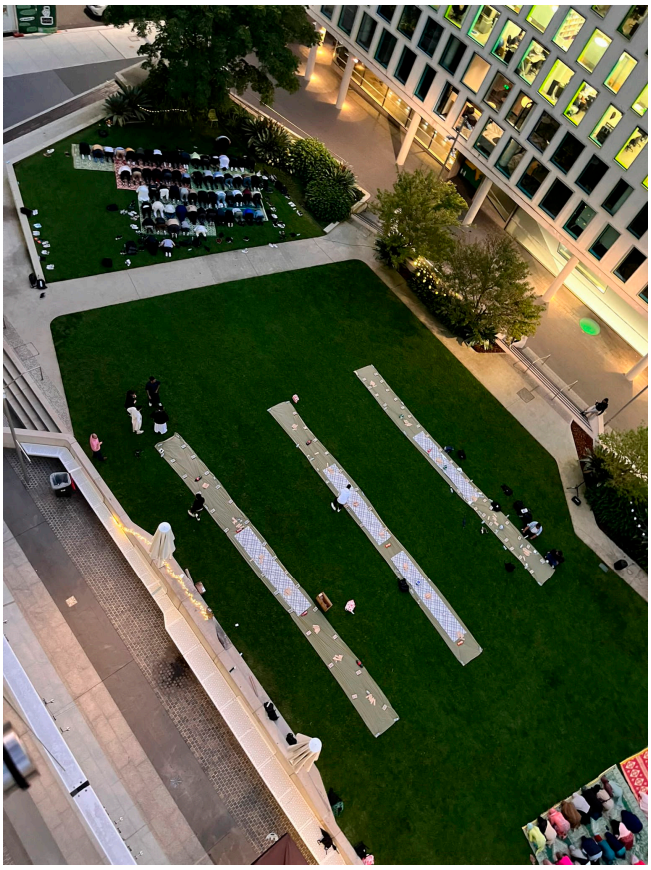

Figure 1. Photo of the Alumni Green at UTS.

It is relatively easy to miss that the space is in fact a green roof, given its level. However, UTS considers the space a green roof and has actively promoted its several sustainable design features [23]. These features include native and drought resistant plants, rainwater capture, construction materials that have low environmental footprints, and resource efficient lighting and irrigation systems.

3.2. Sample and Data Collection

A cross-sectional survey was conducted of users of the UTS Alumni Green (the green roof), consisting of students, staff and the general public (N = 128). Using a convenience sampling approach, participants were recruited between May and July, 2022. First, an email was sent to staff and students whose departments were located immediately vicinity of the green roof. As a result, a total of 61 participants completed the survey. Second, a further 67 participants were recruited via on-site surveys. Due to time limitations, further recruitment of survey respondents was not pursued.

Participants completed the online questionnaire, hosted on the online survey platform Qualtrics, using their own computers or mobile devices. The Qualtrics software helps to design and distribute surveys to identified email lists. The Western Sydney University's Human Research Ethics Committee provided ethical approval to conduct the survey, with consent provided when the participant had read through the participant information sheet and clicked through to begin the survey.

3.3. Measures

3.3.1. Sociodemographic Characteristics

Participants' sociodemographic qualities were recorded, including age, gender and profession. These three characteristics were recorded using categorical variables: age was divided into four categories (18–35, 36–50, 51–65, and over 65 years), as was gender (male, female, non-binary/third gender, and prefer not to say), while profession was divided into three (student, staff, and other). Ultimately, gender was treated as a dummy variable, as participants only selected male and female in their responses. Similarly, only three categories ended up being recorded for age, as only one respondent indicated their age was over 65 years, so the third category was merged to include those over 50 years.

3.3.2. Knowledge of Green Roof

In a similar manner to Jungels, Rakow, Allred and Skelly [20], participants' knowledge of the green roof was measured by asking participants, on a dichotomous 'yes or no' scale, whether they knew the space was, in fact, a green roof. Responses were recorded as dummy variables.

3.3.3. Perceptions of the Roof's Contribution to the SDGs

Based on research indicating that green roofs have the most direct benefits for SDGs 3 (good health and wellbeing), 10 (reduced inequalities), 11 (sustainable cities and communities), 13 (climate action) and 15 (life on land) [24,25], two constructs were developed to evaluate participants' perceptions of the extent to which these SDGs were contributed to. That is, perceptions of the green roof's contributions to the SDGs were recorded across two constructs: social benefits and environmental benefits (reliability of these constructs is reported in Table 1). Each construct consisted of four items. The items were measured by asking participants to what extent they agreed with a series of statements on a scale of one (strongly disagree) to five (strongly agree), with each relating to an individual SDG, similarly to the method conducted by Wey, Sarma, Lechner and Nath [12] in evaluating perceptions of a green space's contribution to the SDGs. For social benefits, the four statements related to the extent to which participants agreed the Alumni Green (the green roof): encourages a healthy lifestyle; is accessible to people of all ages; is a safe and inclusive space; and encourages me to come into and spend time at university. For environmental benefits, the statements were: prompts me to think about nature and sustainable development; minimises the impacts of climate change; promotes action that combats climate change; and protects and maintains biodiversity. Across these two constructs, the four items were summed and averaged. Higher scores indicate the belief that the green roof has a greater contribution to the SDGs.

Table 1. Reliability of the two SDG constructs.

Construct	Number of Items	Cronbach's Alpha
Social benefits (SDGs 3, 10 and 11)	4	0.72
Environmental benefits (SDGs 13 and 15)	4	0.82

3.4. Data Analysis

A total of 128 participants began the survey. Using SPSS, a statistical analysis program, these 128 responses were cleaned, resulting in 24 being removed due to error and missing data (resulting in N = 104). Consistent with Issa et al. [26], the following analyses were undertaken. First, one-way analysis of variance (ANOVA), a statistical test used to determine whether the means of two or more groups differ significantly [27], was employed to explore whether users' perceptions of the roof's environmental and social benefits differed by age and profession. The ANOVA was used for age and profession as

both these variables were recorded across three groups. Second, an independent samples *t*-test, a statistical test considering the difference of means between two groups solely on a continuous variable [28], was conducted to explore whether there were differences in the perception of environmental and social benefits between males and females. Third, and similarly, an independent samples *t*-test was also conducted to determine whether respondents' perceptions of the benefits of the green roof differed by their knowledge of the roof, with the two groups consisting of those who said they knew the space was a green roof and those who did not.

4. Results

4.1. Sample Characteristics

Beginning with gender, people identifying as female (55.8%) formed a slightly higher proportion of the participants than those identifying as male, while for age, the majority of the participants were between 18–35 years (66.30%). A smaller selection was between the ages of 36 and 50 years (25.00%), while very few indicated they were over 50 years (8.70%). It was most common for participants to be university students (61.20%), while academic staff (20.40%) and other occupations (18.40%) were in smaller concentrations. It was very common for participants to say they were familiar with the Alumni Green (83.70%), whereas only 43.40% of the sample knew that the space was a green roof.

4.2. Respondents' Views on the Roof's Contribution to the SDGs

Table 2 presents the results of the survey of participants' views of the green roof's contribution to the SDGs. Respondents rated the social benefits of the roof more strongly than the environmental benefits, and saw its greatest benefits as being its accessibility, safety, and inclusivity. Participants were less sure that the roof promoted action to combat climate change and protect biodiversity.

Table 2. Means for each component of the two SDG constructs.

Construct/Characteristic	M (Mean)	SD (Standard Deviation)
Social benefits	2.94	0.58
Encourages a healthy lifestyle	2.76	0.56
Accessible to people of all ages	2.97	0.87
Safe and inclusive	3.08	0.66
Encourages me to come into and spend time at the university	2.60	0.90
Environmental benefits	2.41	0.56
Prompts me to think about nature and sustainable development	2.53	0.82
Minimises impacts of climate change	2.36	0.77
Promotes action that combats climate change	2.31	0.76
Protects and maintains biodiversity	2.33	0.89

4.3. Sociodemographic Characteristics and Perceptions of the SDGs

Table 3 presents the results of the ANOVAs and independent samples *t*-tests conducted to explore whether there were differences between the various sociodemographic characteristics and perceptions of the green roof's contribution to the SDGs. The one-way Welch ANOVA conducted to explore if the perceptions of the green roofs' sustainable development impacts differed by profession (student, staff or other) was statistically significant for the social benefits, $F(2, 74) = 3.16$, $p < 0.05$. The scores across each of the groups for the social benefits were student ($M = 3.02$, $SD = 0.56$), staff ($M = 2.65$, $SD = 0.64$), and other ($M = 3.04$, $SD = 0.50$). Tukey post hoc analysis revealed that the mean difference between student and staff (0.37, 95% CI [−0.00, 0.75]) was statistically significant ($p < 0.05$), while the mean differences between student and other (−0.02, 95% CI [−0.42, 0.38]) and staff and other (−0.39, 95% CI [−0.86, 0.07]) were not. The results of the ANOVA conducted for profession and perceptions of environmental benefits were not statistically significant with $F(2, 73) = 1.91$, $p > 0.05$. The scores for environmental benefits across each of the

groups were: student (M = 2.46, SD = 0.51), staff (M = 2.15, SD = 0.72), and other (M = 2.50, SD = 0.73).

Table 3. Differences between groups for sociodemographic characteristics and perceptions of the roof's contributions to the SDGs.

Characteristic	Social Benefits			Environmental Benefits		
	M (Mean)	SD (Standard Deviation)	*p*	M (Mean)	SD (Standard Deviation)	*p*
Profession						
Student	3.02	0.56	0.05 *	2.46	0.51	0.16
Staff	2.65	0.64		2.15	0.72	
Other	3.04	0.50		2.50	0.73	
Age						
18–35 years	2.98	0.52	0.38	2.44	0.51	0.25
36–50 years	2.94	0.69		2.47	0.76	
Over 51 years	2.67	0.67		2.06	0.74	
Gender						
Female	2.92	0.62	0.45	2.46	0.67	0.46
Male	2.96	0.55		2.34	0.56	

Note: * denotes $p < 0.05$.

The ANOVAs conducted to determine if perceptions of the SDGs changed by participants' age were not statistically significant for social or environmental benefits. For social benefits, the scores were similar among the ages of 18–35 years (M = 2.98, SD = 0.52) and 36–50 years (M = 2.94, SD = 0.69), while those over 51 years rated the benefits as lower (M = 2.67, SD = 0.67), with the overall ANOVA statistically insignificant, $F(2, 75) = 0.98$, $p > 0.05$. Likewise, for environmental benefits, those aged 18–35 years (M = 2.44, SD = 0.51) and 36–50 years (M = 2.47, SD = 0.76) scored similarly, while those aged over 50 years averaged less (M = 2.06, SD = 0.74), with the ANOVA again not achieving statistical significance, $F(2, 74) = 1.40$, $p > 0.05$.

The independent samples t-tests conducted to explore whether perceptions of the environmental and social benefits of the green roof differed by gender also did not obtain significant results. For social benefits, females (M = 2.92, SD = 0.62) perceived the impact as slightly lower than males (M = 2.96, SD = 0.55), although this difference was not statistically significant, $M = 0.04$, 95% CI [−0.30, 0.23], $t(76) = -0.27$, $p > 0.05$. Similarly, for environmental benefits, the difference between females (M = 2.46, SD = 0.67) and males (M = 2.34, SD = 0.56) was not statistically significant, $M = 0.12$, 95% CI [−0.15, 0.41], $t(75) = -0.87$, $p > 0.05$.

4.4. Knowledge of the Green Roof and Perceptions of the Roof's Contribution to the SDGs

Table 4 presents the results of the independent samples t-tests conducted to examine whether there were differences in respondents' perceptions of the extent to which the green roof contributes to both social and environmental benefits, between those who knew the space was a green roof and those who did not know. Participants who had prior knowledge that it was a green roof rated the environmental benefits as higher (M = 2.46, SD = 0.73) than those who did not know (M = 2.36, SD = 0.53). This difference was statistically significant, $M = 0.10$, 95% CI [−0.39, 0.19], $t(74) = -0.71$, $p < 0.05$. In contrast, in the independent samples t-test conducted for perceptions of the social benefits of the green roof, participants who knew the space was a green roof perceived the impact as less (M = 2.81, SD = 0.64) than those who did not know (M = 3.02, SD = 0.53). This difference was not statistically significant, $M = 0.21$, 95% CI [−0.06, 0.47], $t(74) = 1.56$, $p > 0.05$.

Table 4. Differences between groups for knowledge of the green roof and perceptions of the contribution to the SDGs.

Construct	Green Roof Knowledge (Yes)		Green Roof Knowledge (No)		
	M (Mean)	SD (Standard Deviation)	M (Mean)	SD (Standard Deviation)	*p*
Social benefits	2.81	0.64	3.02	0.53	0.19
Environmental benefits	2.46	0.73	2.36	0.53	0.03 *

Note: * denotes $p < 0.05$.

5. Discussion

This paper reports on green roof users', predominantly university students and staff, perceptions of the extent to which the green roof contributes to the SDGs. The analysis revealed that users' perceptions did not largely differ by sociodemographic characteristics, although students perceived the social benefits of the green roof as greater than university staff. Beyond this, those who had the knowledge that the space was a green roof were more likely to perceive the contribution of the roof to environmental SDGs as greater, but not the social SDGs.

In finding that students perceived the social benefits of the green roof as greater, this research adds to the growing body of literature revealing that university students may be more positive about the impacts of green infrastructure [12,17,20], when compared to university staff and those outside universities. For the notion that green infrastructure within university campuses is particularly important for encouraging positive perceptions of sustainable development and encouraging future action towards sustainability as students are more open to such opinions [13], these findings offer support. However, findings elsewhere that women and younger people also perceive the impacts of green infrastructure as greater [12,17,20], were not repeated here. Given this is a university campus and the vast majority of users of the green roof were younger people, there was only a small selection of participants over 51 years included in this present study. As a result, it is possible that the ability to differentiate by age was reduced and it is completely possible that, should more elderly people have been included in the study, age would have been observed to correlate with perceptions. Given the gender balance was fairly evenly split in the present study, it was somewhat surprising that females were not found to have significantly higher perceptions of the impacts of the green roof. However, the only other study conducted exploring perceptions of green roofs on university campuses also found that gender did not play an influential role [20], so perhaps gender differences regarding the impacts of green infrastructure are less pronounced in university contexts.

Likewise, supporting other research indicating that knowledge influences an individual's perceptions of green infrastructure [15,20], we found that those who had knowledge of the green roof rated the environmental benefits as greater. While Jungels, Rakow, Allred and Skelly [20] just focused on perceptions of environmental impacts of green roofs, our present study extended this to also include social benefits. However, those who had more knowledge of the green roof, did not perceive the social benefits as greater. More broadly, promoting knowledge and awareness of green roofs and their environmental contributions could contribute to more positive perceptions and attitudes toward such green infrastructure, as has been asserted elsewhere [17]. For university campuses, then, such green initiatives are likely to advance their progress towards the SDGs whilst also promoting broader education and awareness of their environmental impacts.

Finally, the fact that participants perceived the social and environmental contributions of the green roof varyingly is of interest. That is, students were more likely to perceive the social benefits as greater, while those with more knowledge of the green roof rated the environmental benefits more highly. Students may perceive the social impact more positively than non-students because they were more likely to use the roof for social purposes [9], invoking notions of socialisation and peer interaction. While it is intriguing

that those with knowledge of the green roof did not perceive both the environmental and social impacts of the green roof as greater than those with less knowledge, this could be for a few reasons. First, as the narrative around the green roof promoted by the university predominantly focused on its environmental features and performance [23], those who have knowledge of this narrative may then be more focused on the roof's contribution to the environmental SDGs rather than social. Second, as the majority of the sample used the space for social purposes [9], more people may have been aware of the possible social impacts than environmental, thus reducing the role of knowledge.

6. Conclusions

This research has asserted that universities are well placed to adopt and use the SDGs on their campuses both to educate and to showcase how the SDGs can be delivered in the built environment. Green infrastructure, in the form of green roofs, green walls or green spaces, are highly visual and contribute to the SDGs such as 3 (good health and wellbeing), 10 (reduced inequalities), 11 (sustainable cities and communities), 13 (climate action) and 15 (life on land). UTS, located in the Sydney central business district, has embraced adoption of green infrastructure in recent campus upgrades undertaken from the mid-2010s and this has been reflected in students increased awareness of green infrastructure and its contribution to sustainable development.

Furthermore, these green infrastructure features are, and can be, referenced in teaching and learning about sustainability in many university courses. The finding that university students were more positive about the social impacts of the green roof indicates that universities are particularly good places for such teaching and learning to occur, as students may be more open to such messaging. Further supporting this was the finding that those who were more knowledgeable of the green roof also considered the environmental impacts to be more positive, indicating again the importance of educational activities to pair with green infrastructure to increase such knowledge.

In summary, we assert that education and information should accompany the implementation of any green roof, as this knowledge would further enhance the enjoyment of users and the extent to which they value the space and perceive its benefits. This knowledge is transferable and relevant to building owners of commercial, residential, and public space and highlights the benefits of communicating information about environmental features that might not be immediately obvious to most people. In this way we can maximise people's perceptions and enjoyment of social and environmental attributes of green infrastructure in urban environments.

As with all studies, there are some limitations which need noting. First, this study was conducted during the time when COVID restrictions were slowly being eased. Many universities were still conducting their operations online. Therefore, the sample is relatively small. It is possible that the results are not generalisable to the wider population. Second, given only one green roof was examined, with its own unique qualities and characteristics, the results need to be interpreted carefully. Future studies could compare user attitudes across different types of green roofs. Finally, the use of Likert scale has its own limitations. As pointed out by other researchers [29], responses in this study center around the midpoint. Future research using a qualitative framework could help reveal deeper insights into users' attitudes.

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Data Availability Statement: The data is deposited in Western Sydney University's Data Repository managed by the Library, WSU.

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