Drivers for the adoption of circular water systems at the building level in a high-income context

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ARTICLE INFO

ABSTRACT

Circular water systems at the building level offer potential for sustainable water management. Yet, user acceptance and willingness to pay (WTP) challenge their adoption. This study explores factors shaping acceptance and WTP by surveying 496 respondents on attitudes toward circular water systems and maintenance preferences. In addition, 76 visitors to the KREIS-Haus, a living lab in Switzerland, were surveyed to examine the influence of direct experience with circular water and building practices. Environmental awareness emerged as the most consistent predictor of acceptance of and WTP for circular water systems, while factors including living arrangement, environmental knowledge, dwelling size, and gender were significant in specific contexts. Among the circular practices presented, the use of treated rainwater as potable water, received the highest acceptance. Practices related to the nutrient cycle, such as composting toilets and producing fertiliser from human waste, were less accepted. About half of the respondents were open to participating in gardening (47 %) and minor technical maintenance (50 %), while preferring to outsource compost toilet management. Preferences were shaped by hygiene concerns, perceived effort, and fairness in task distribution. Visiting the KREIS-Haus increased acceptance and WTP, indicating a positive effect of experiential learning. These findings highlight the importance of combining behavioural, organisational, and contextual factors to enhance acceptance. Future research should explore the structure and long-term feasibility of maintenance models and whether stated acceptance leads to actual behavioural change.

1. Introduction

The global water crisis, exacerbated by urbanization, climate change, and population growth, has intensified the need for innovative water management strategies (Capodaglio, 2024; He et al., 2021). Even in countries like Switzerland, traditionally not associated with water scarcity, climate change is causing regional and seasonal water shortages by altering rainfall patterns (Fischer et al., 2015) and reducing glacier and snow cover (Brunner et al., 2019). In this light, recent research explores a variety of strategies for sustainable water management that support the transition from linear to circular systems, in which water is reused and resources such as nutrients and energy are recovered (Frijns et al., 2024). Enhancing sustainability and resilience in urban water supply under increasing climate variability will require redesigning systems, diversifying sources, and improving efficiency (Capodaglio, 2024). Alongside circular water management, measures such as rainwater harvesting, stormwater reuse and desalination can improve resource use, but they must be coupled with demand reduction and solutions tailored to local climatic, economic, and social contexts (Capodaglio, 2024).

While circular approaches can be implemented at both centralised and decentralised levels, decentralised systems may offer distinct advantages in terms of adaptability, cost-effectiveness, and environmental sustainability, as they facilitate simpler local resource recovery and enable more flexible responses to climate and demographic changes (Beutler et al., 2024). At the most localised end of the decentralisation

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spectrum, the building level offers the potential for an effective implementation of circular water systems through source separation of wastewater streams, incorporating and reusing alternative water sources such as rainwater and greywater, and treating these streams to the required water quality for reuse (Capodaglio, 2021; Otterpohl et al., 2004; Wanjiru & Xia, 2018). Mixed centralised sewers dilute influent, reducing the efficiency of energy and nutrient recovery, whereas source separation and fit-for-purpose treatment at building scale can enhance recovery and reuse outcomes (Capodaglio, 2020). Source separation entails collecting wastewater at the point of generation, enabling targeted treatment and reuse. Domestic wastewater can be separated into greywater (from showers, baths, kitchens, washing machines), blackwater (toilet wastewater), yellow water (urine), and brown water (faeces) (Baykal, 2019; Otterpohl et al., 2004). Such separation allows for tailored recovery strategies, for example extracting energy and nutrients from blackwater through anaerobic digestion, or processing urine into fertiliser. Integrating urban farming can further close resource loops by using treated wastewater for irrigation and applying urine-derived fertiliser, while reducing environmental impacts such as transport-related emissions from conventional crop cultivation (Garrido-Baserba et al., 2024). Throughout this study, the term "circular water system" will be used to refer to such decentralised, reuse-oriented approaches to the water cycle at the building level.

Approaches to circular water management can be classified into (1) substitution, such as using rainwater or greywater for non-potable uses; (2) regeneration, such as on-site treatment to produce reusable water; and (3) reduction, such as installing water-efficient fixtures or a dry toilet (Grant et al., 2012). To achieve holistic sustainability at the building level, it is important to integrate sustainable practices beyond water-related practices, such as renewable energy or ecological building materials. Combining these elements early in the design process can create synergies, improve performance, and help manage complexity through collaboration and systems thinking (Buehler et al., 2025b; Kamari, 2023).

Quezada et al. (2016) identified a potential shift in the Australian water industry from a government-supported centralised model to a decentralised approach. However, the authors emphasise that there is still a need for collaborative strategies to develop new socio-technical systems that reconcile economic tensions with neoliberal, social, and environmental goals in order to achieve social equity, resource efficiency, and broader planning outcomes (Quezada et al., 2016).

Maniam et al. (2022) identified multiple factors influencing the uptake and implementation of circular water systems, including technology readiness, implementation and maintenance costs, water quality characteristics, availability of space and infrastructure, user awareness and acceptance, as well as regulatory standards and support mechanisms. In terms of technical factors, proper operation, maintenance, and water quality monitoring are critical for the safe and sustained adoption of circular water systems, particularly when managed at household or community level, as responsibilities are shifted to local actors and end users (Contzen et al., 2023; Maniam et al., 2022).

Successful implementation relies on users' positive valuation and, depending on the technology and scale of implementation (household, cluster, or neighbourhood), can involve different levels of use. 'Passive' use, rooted in acceptance, typically occurs at the neighbourhood or cluster scale, for example by drinking treated water provided by the system. 'Engaged' use, rooted in support, may occur at the cluster or household level, for example by contributing financially to installation or maintenance. 'Active' use, rooted in behaviour change, applies at the household level, for example by operating and maintaining the system. (Contzen et al., 2023). Contzen et al. (2023) further emphasise the importance of distinguishing between these levels and call for future research to prioritize studies that promote decentralized water treatment. Such community-based approaches to sanitation service delivery are increasingly being adopted in low- and middle-income countries, where participatory methods at the community and household levels

have demonstrated success in enhancing local ownership, promoting behaviour change, and improving the sustainability of decentralised sanitation systems (Lüthi et al., 2009).

The successful adoption of circular water systems also depends on users' willingness to pay (WTP) for installation, operation, and maintenance. Studies in low- and middle-income countries have shown that social dynamics and perceived benefits play an important role. For example, Cecilia et al. (2024) found that in Indonesia, households' willingness to pay for wastewater treatment system maintenance increased with a sense of community ownership and was higher when service improvements, such as facility upgrades and enhanced effluent quality, were evident. Deh-Haghi et al. (2020) examined Iranian farmers' WTP for using treated wastewater in agricultural irrigation. They found that 56 % of farmers were willing to pay the same price as freshwater, 18.3 % were willing to pay the highest proposed price, and 91.7 % were willing to pay at the lowest price level. Users generally expect treated wastewater to be the same price or cheaper than conventional sources (Deh-Haghi et al., 2020; Roopnarine et al., 2023).

While previous studies in Switzerland have examined stakeholder preferences regarding centralised and decentralised wastewater systems (Aubert et al., 2022; Kuller et al., 2023; Zheng & Lienert, 2018) and urban water reuse (Knabl et al., 2024), research on user-level engagement remains limited. Specifically, little is known about users' willingness and preference to take on or outsource maintenance tasks, their willingness to pay for such services, or the conditions that shape these preferences. Furthermore, the role of direct exposure to circular water systems in influencing acceptance and WTP, as well as the relative acceptance of circular water systems compared to other sustainable building practices, remain underexplored.

This study examines these identified gaps through the lens of the KREIS-Haus, an innovative living lab in Switzerland that integrates a circular water system and sustainable building practices, such as solar energy and ecological building materials (Buehler et al., 2025b). Its dual functionality as a research facility and a vacation rental enables the exploration of user engagement with a circular water system. The study investigates how direct user experience, particularly through 'active use' of the system, along with preferences for maintenance organisation, socio-economic factors, and users' preferences for circular water systems compared to other sustainable building practices, influence acceptance of circular water systems. We also explore respondents' stated willingness to pay ranges for outsourcing preferred maintenance tasks and, more broadly for a sustainable home. This focus aligns with calls to foster exploratory research to uncover new patterns and hypotheses in underexplored domains (Swedberg, 2020). Thus, this study analyses the potential of circular water systems in a high-income country such as Switzerland with limited exposure to water scarcity. The remainder of this manuscript describes the methodology applied in this study, followed by a description of the results and the concluding remarks.

2. Materials and methods

This study adopts an exploratory research approach (Swedberg, 2020) to investigate user preferences, acceptance, and WTP for circular water systems, focusing on maintenance organisation, engagement levels, and the influence of direct experience. Acceptance refers to a respondent's general openness to adopting a specific technology or practice, regardless of available alternatives (Ahn et al., 2015), whereas preferences refer to comparative evaluations between multiple options or features, such as prioritizing one sustainable practice over another (Barinaga-Rementeria et al., 2019).

The analysis begins by examining broader public attitudes through a survey inspired by the circular water system implemented at the KREIS-Haus living lab (Section 2.2). Living labs are increasingly recognised as effective tools to accelerate innovation and adoption of sustainable building technologies (Molinari et al., 2023). Therefore, the study

further explores how direct exposure, as experienced by KREIS-Haus visitors, influences acceptance and engagement. Survey data were analysed using summary statistics (Section 2.4.1), indices derived from aggregated responses (Section 2.2), ordinal logistic regression (Section 2.4.2), and comparative analysis to examine relationships among key variables (Section 2.4.3).

2.1. KREIS-Haus living lab

Living labs provide unique spaces to engage users in real-world environments, enabling the study of behavioural responses, operational challenges, and user acceptance through co-creation and iterative feedback processes (Molinari et al., 2023). The KREIS-Haus is one such living lab designed to demonstrate and test innovative circular water and building practices (Buehler et al., 2025b). Established in 2021 in Feldbach, a village at Lake Zurich in the German-speaking part of Switzerland, it integrates a circular water system with a comprehensive range of sustainable building practices within a compact footprint, including ecological building materials, circular construction techniques, space-saving design, and renewable energy solutions.

The facility comprises a residential space, a conservatory, and a technology room. At the core of the circular water system is an off-grid, self-sufficient water cycle system based on source separation, treatment and reuse of the different wastewater streams. Greywater is treated and reused for non-potable purposes, such as irrigation and laundry, while rainwater is harvested, treated, and used for bathroom and kitchen applications. Nutrient recycling is facilitated by a dry separating toilet, from which the faeces are composted and the urine processed into a fertiliser. The resulting compost and fertiliser, together with treated greywater, are used to grow crops in the indoor rooftop garden. Pictures, floor plans and the concept of the water cycle are presented in Fig. 1. Further technical details are provided in (Buehler et al. 2025a, Buehler et al. 2025b). Beyond its technical innovation, the KREIS-Haus provides a real-world environment where visitors can engage directly with sustainable living practices by renting the house as a vacation accommodation.

2.2. Survey design

A structured survey was designed to explore the research focus outlined in the previous sections. The questionnaire was developed based on insights from existing literature, expert input from the building sector, and findings from eight semi-structured qualitative interviews with potential users (details in Supplementary Material, Table S1). The questionnaire comprised the following sections with questions related to (A) knowledge of sustainable water systems, (B) values, attitudes, and behaviour, (C) maintenance organisation, (D) sustainable building practices, and (E) demographic and background information. Sections A and D were tailored to two target groups: the "affiliated group", consisting of respondents who had stayed overnight at the KREIS-Haus, and the "unaffiliated group", comprising respondents with no prior experience of the house. Section A was adapted for the affiliated group by asking them to indicate their level of knowledge prior to their stay at the KREIS-Haus. In section D, the affiliated group answered questions referring directly to technologies and practices implemented in the KREIS-Haus, while the unaffiliated group received a generalised version of these questions. The questionnaire featured a range of question types, such as Likert scales, dichotomous (yes/no), multiple choice, ranking, and matrix formats. The survey was conducted in German, programmed using the *Onlineumfragen* tool, and distributed in digital format. The full questionnaire is available in the Supplementary Material, Table S3.

A set of independent and dependent variables were defined (Supplementary Material, Table S2) and used for both an ordinal logistic regression (section 2.4.2) and a Wilcoxon rank-sum test to examine the influence of direct experience on the dependent variables (section 2.4.3). The dependent variables represent the outcomes to be explained (e.g., WTP, acceptance), while the independent variables capture factors expected to influence these outcomes. The dependent variables encompassed general acceptance of sustainable technologies (short: general acceptance), acceptance of circular water technologies/practices (short: water acceptance), willingness to pay for sustainable technologies (short: WTP general) and willingness to pay for outsourcing maintenance services (short: WTP maintenance). The independent variables, derived from literature (Supplementary Material, Table S2), included demographic and socio-economic factors, specifically age, gender, professional sector, level of education, income, monthly rental/
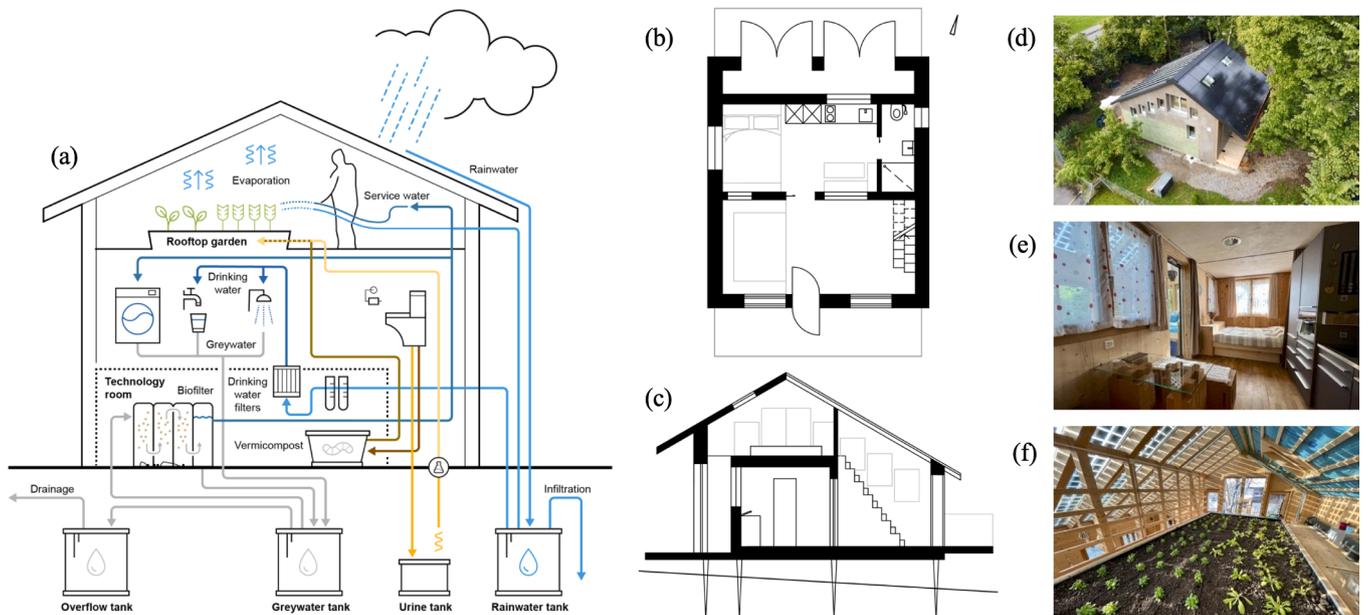

Fig. 1. Impressions of the KREIS-Haus. (a) Conceptual diagram of the closed water and nutrient cycle, (b) ground-floor plan showing the layout of the living space, conservatory and technology room, (c) cross-section, (d) exterior north view from above, (e) interior view of the living space with kitchen and bed, (f) rooftop garden in the conservatory used for food production as well as water and nutrient reuse. Adapted from Buehler et al. (2025b).

housing costs, dwelling size (area), living arrangement (e.g., alone, with partner, parents), household size (number of persons), and area type (urban, agglomeration, rural), as well as attitudinal and experiential factors, namely environmental awareness, environmental experience, environmental knowledge, and technological interest.

It is important to notice that our WTP variables are range-based responses that provide structure to the data and allow us to analyse the distribution of preferences. These can serve as an initial indicator or screening tool for more in-depth valuation studies, but they should not be considered a precise or robust WTP estimate comparable to those from contingent valuation or discrete choice experiments.

2.3. Participant selection and data collection

The unaffiliated group was recruited using a purposive sampling approach (Palinkas et al., 2015), as respondents were selected to represent Swiss tenants without prior exposure to the KREIS-Haus. The survey was distributed in collaboration with a large real estate owner, who facilitated access to this target group via building administrators. The survey was conducted in January 2023 with a total of 496 respondents across the German speaking part of Switzerland.

The affiliated group consisted of individuals who had stayed overnight at the KREIS-Haus and completed the online survey after their visit. This data collection spanned from June 2022 to October 2024 and involved 76 respondents. The response rate was approximately 40 %. This reflects a convenience sampling approach, as the research team had no control over who stayed at the KREIS-Haus. The responses from this group were specifically utilised to assess a potential impact of direct experience on the acceptance and willingness to pay for circular water systems.

Table 1
Summary statistics of the demographic and socio-economic characteristics of the study sample, compared to Swiss average.

Variable (# respondents: unaffiliated total, unaffiliated subset, affiliated)	Category	Unaffiliated group total (% [95 % CI])	Unaffiliated group subset (%[95 % CI])	Affiliated group (%[95 % CI])	Swiss average (%)	Swiss average Year (Reference)
Age (#: 384, 68, 64)	15–24	2 (1–4)		3 (0–11)	12	Year 2023 (BFS, 2025a)
	25–34	26 (21–30)	24 14–36)	20 (11–32)	16	
	35–44	**27 (22–31)**	**27 (17–39)**	22 (13–34)	17	
	45–54	16 (13–20)	19 (11–31)	**27 (16–39)**	16	
	55–64	12 (9–16)	13 (6–24)	14 (7–25)	16	
	> 65	17 (13–21)	17 (8–28)	14 (7–25)	**23**	
Gender (#: 380, 68, 65)	Female	37 (32–42)	49 (37–62)	**49 (37–62)**	50.3	Year 2023 (BFS, 2024a)
	Male	**62 (57–67)**	**51 (38–63)**	48 (35–60)	49.7	
	Non-binary	1 (0–2)		3 (0–11)	-	
Education (#: 379, 67, 64)	Still in compulsory school					Year 2023 (BFS, 2024b)
	No compulsory school leaving certificate					
	Compulsory school	1 (0–2)	1 (0–8)		14	
	Preliminary vocational training	0.3 (0–1)		2 (0–8)		
	Apprenticeship	22 (18–27)	22 (13–33)	8 (3–17)	**33**	
	Vocational maturity, Diploma / Specialised middle School	8 (6–11)	3 (0–10)	8 (3–17)	7	
	Advanced vocational and professional education	29 (24–34)	29 (90–41)	20 (11–32)	15	
	University / Polytechnical university / University of applied sciences	**40 (35–45)**	**45 (33–57)**	**62 (50–74)**	31	
Annual Gross Income (CHF) (#: 338, 63, 51)	No income	1 (0–3)		6 (1–16)	81456 (median)	Year 2022 (BFS, 2024e)
	1–20′000	3 (2–6)	3 (0–11)			
	20′000–40′000	4 (2–6)	5 (1–13)	6 (1–16)		
	40′001–60′000	11 (8–15)	11 (5–22)	21 11–35)		
	60′001–80′000	17 (13–21)	21 (11–33)	16 (7–29)		
	80′001–100′000	**23 (18–27)**	17)9–29)	**17 (8–31)**		
	100′001–120′000	18 (14–23)	**22 (13–34)**	12 (4–24)		
	120′001–150′000	14 (11–18)	8 (3–18)	16 (7–29)		
	> 150′000	9 (6–12)	13 (6–23)	6 (1–16)		
Living Environment (#: 384, 67, 65)	City	35 (30–40)	36 (25–48)	**60 (47–72)**	63	Year 2023 (BFS, 2024c)
	Rural	21 (17–26)	16 (8–26)	19 (10–30)	15	
	Suburban	**44 (39–49)**	**48 (36–61)**	21 (12–33)	22	
Household Size, number of persons (#: 381, 66, 64)	1	36 (31–41)	**33 (22–45)**	23 (14–26)	**37**	Year 2023 (BFS, 2024d)
	2	**39 (34–44)**	30 (20–42)	**50 (37–63)**	33	
	3	14 (11–18)	17 (9–28)	11 (5–21)	30	
	4	10 (8–14)	19 (10–30)	13 (6–23)		
	≤ 5	1 (0–2)	1 (0–8)	3 (0–11)		
Rent in CHF (#: 369, 65, 56)	≤ 500	1 (0–3)		4 (0–12)	1451 (average)	Year 2023 (BFS, 2025b)
	501–1000	2 (1–4)	2 (0–8)	23 (13–36)		
	1001–1500	13 (9–16)	13 (6–23)	19 (10–32)		
	1501–2000	**36 (31–41)**	**37 (26–50)**	**34 (22–48)**		
	2001–2500	34 (29–39)	34 (23–47)	9 (3–20)		
	2501–3000	10 (7–14)	7 (2–16)	5 (1-15)		
	3001–3500	3 (1–5)	6 (2–14)	2 (0–10)		
	3501–4000	1 (0–3)	1 (0–8)	2 (0–10)		
	> 4000			2 (0–10)		

Notes: Values in parentheses in the first column indicate the number of respondents in (i) the unaffiliated total, comprising all respondents with no prior experience of the KREIS-Haus, (ii) the unaffiliated subset, a sample of unaffiliated respondents closely matching the characteristics of the affiliated group, and (iii) the affiliated group, consisting of individuals who stayed overnight at the KREIS-Haus and completed the online survey after their visit. Values in parentheses in the third to fifth column are 95 % confidence intervals (CI; Clopper–Pearson exact). Bolded values indicate the most represented category within each variable.

Neither group received any form of incentive for completing the survey. All collected data was anonymised. The study underwent ethical evaluation in accordance with the procedure of the Zurich University of Applied Sciences. A comparison of the demographic and socio-economic characteristics of both groups with the Swiss average is presented in Section 3, Table 1.

2.4. Data analysis

2.4.1. Summary statistics

Summary statistics were used to describe the demographic and socio-economic characteristics of the study sample, analyse respondents' preferences for ecological building practices, assess preferences regarding personal engagement versus outsourcing of maintenance tasks and willingness to pay for outsourcing, and examine the factors influencing respondents' willingness to engage in maintenance tasks. These statistics offer an overview of trends and distributions within the study sample, providing a basis for further analysis and interpretation.

2.4.2. Exploratory analysis with ordinal logistic regression

Ordinal logistic regression was applied to explore relationships between the dependent and independent variables in the unaffiliated group. The regression was implemented in R software version 4.4.3 (The R Foundation, 2025) using the polr() function from the MASS package (Rdocumentation, 2025b). It estimates the probability that a dependent variable Y falls into a specific category k or below, based on a set of independent variables X_1, X_2, ..., X_n. The cumulative logit for each threshold k is modelled in formula 1, where $P(Y \leq k)$ is the cumulative probability of Y being in category k or lower, $\beta_0^{(k)}$ is the intercept for threshold k, $\beta_1, \beta_2, ..., \beta_n$. are the coefficients for the independent variables, and X_1, X_2, ..., X_n represent the independent variables. All numeric independent variables were standardised before analysis. Nominal variables such as gender and area type were left untransformed. Multicollinearity was checked prior to model fitting (see Supp. Materials, Figure S1). Results were reported with coefficients (β), standard errors (SE), z-values, and p-values. Statistical significance was assessed at $|z| > 2$ and p < 0.05, 0.01 and 0.001.

It is important to note that our model does not account for all potential confounding factors, and as such, no causal relationships can be inferred. Given the exploratory nature of this study, this limitation does not hinder the investigation of our research question; however, care must be taken not to draw conclusions beyond what the analysis can support.

$$log\left(\frac{P(Y \leq k)}{P(Y > k)}\right) = \beta_0^{(k)} + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_n X_n \qquad (1)$$

2.4.3. Impact of direct experience with comparative analysis

To analyse the potential impact of direct experience, we compared responses from the affiliated group with those from the unaffiliated group. A subset of the unaffiliated group was isolated to match the characteristics of the affiliated group as closely as possible. For this purpose, matching was performed on the variables environmental knowledge, awareness, and experience, under the assumption that KREIS-Haus visitors would show higher acceptance of sustainable practices due to their demonstrated interest and willingness to pay for an experience at KREIS-Haus. To minimise the loss of observations due to missing values, the subgroup was not fully matched on all variables. Matching was performed in R software version 4.4.3 (The R Foundation, 2025) using the matchit() function from the Matchit package (Rdocumentation, 2025a). Table S4 in the Supplementary Material provides an overview of all variables for both groups, including statistical test results. The Wilcoxon rank-sum test (also known as the Mann–Whitney U test) was used to assess differences in general acceptance, water acceptance, WTP general and WTP maintenance between both groups. Statistical significance was evaluated at p < 0.05, 0.01 and 0.001.

This methodological approach aimed to ground the comparison between the two groups with similar characteristics. However, it should be noted that this comparison is made using an unpaired sample, meaning that the two groups were not matched on all potential confounding variables. This could introduce variability into the results, as the unpaired nature of the sample means that differences in outcomes between the two groups could stem from other unmeasured factors besides just their experience with KREIS-Haus. In addition, the sample size of 62 to 76 in each group was rather small, as the applied methodology reduces the samples to equal group sizes. Therefore, the results must be interpreted with caution.

3. Results and discussion

3.1. Profile of respondents

This section presents an overview of the demographic and socio-economic characteristics of the study samples, including the total unaffiliated group, the affiliated group, and the subset of the unaffiliated group used for comparison in section 3.4. For context, we also report data from the general Swiss population to facilitate comparison. Differences were observed in age, gender distribution, education level, living environment, and rent costs (Table 1). Respondents across all three groups were primarily within middle age ranges, while the Swiss average shows a more even distribution across younger and older age groups. The unaffiliated group had a higher proportion of male respondents, while the other two groups were closer to the Swiss average. More respondents in this group also lived in suburban areas, whereas the affiliated group was predominantly urban based. In terms of education, all groups had a higher share of university degrees, and a lower proportion of apprenticeship qualifications compared to the national average, with this difference being most pronounced in the affiliated group. Rent expenses were generally above the Swiss average in all groups; however, the affiliated group also included a larger fraction of respondents with very low rental costs. These differences should be considered when interpreting the study findings, as the sample is not fully representative of the Swiss population

3.2. Acceptance and preferences for circular water systems

3.2.1. Preferences across different sustainable building practices

Fig. 2 details respondents' preferences of the unaffiliated group for sustainable building practices, including substitution/regeneration of water sources (use of treated rainwater and greywater), reduction of water demand (dry toilet) and closing of nutrient cycle (fertiliser from faeces). The use of treated rainwater as potable water emerged as the most popular choice, with 80 % of respondents endorsing its use either unconditionally, with reservations, or as a practice they already implement. The reuse of treated wastewater for irrigation was also favourably received, with 67 % of respondents supporting it as a moderately preferred option. In contrast, measures related to water demand reduction and the nutrient cycle, such as dry toilets and the use of human waste as fertiliser were less favoured, with 65 % and 59 % of respondents opposing them, respectively.

Among practices not related to the building water cycle, ecological building materials received the highest preference (70 %), followed by the integration of solar power solutions (69 %), reflecting findings from other studies that highlight high acceptance of solar energy (Azarova et al., 2019; Vuichard et al., 2021). The high support for water cycle measures is somewhat unexpected, given that Switzerland, often called the "water castle" of Europe, does not frequently face water scarcity. However, a cultural appreciation for water may drive recognition of its value and support for its sustainable use (Schneider, 2015). In contrast, acceptance of nutrient cycle measures, such as composting toilets and fertiliser from faeces, remains low, despite their potential for substantial
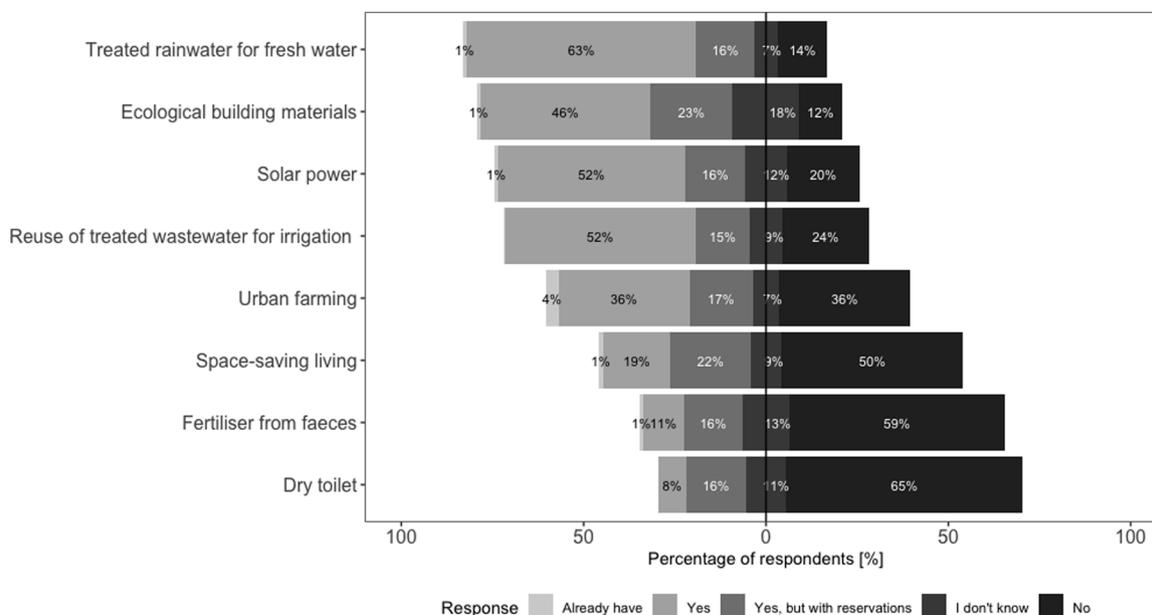
Fig. 2. Preferences of ecological building practices of unaffiliated group. Answers to the survey question "Which of the following technologies / practices of sustainable living would you like to use or implement yourself?" (n = 434). Bars to the left summarise a positive attitude, including the answers "Already have", "Yes" and "Yes, but with reservations", while bars to the right summarise a negative attitude "No". "I don't know" responses are split equally, as it could indicate either a positive or a negative attitude.

water savings. This could be due to the natural aversion to handling human waste, known as the "yuck factor" (Ricart and Rico, 2019). In addition, a lack of public awareness about the environmental benefits could play a role. Some studies found that perceived benefits have a greater influence on acceptance than risks (e.g. Segrè Cohen et al., 2020), while other studies found the opposite (e.g. McConville et al., 2023). The balance appears to be context dependent and is shaped by factors such as application of the fertiliser for edible or non-edible crops, the perceived level of contact or exposure, concerns about product safety, and feelings of disgust or stigma (McConville et al., 2023; Segrè Cohen et al., 2020; Simha et al., 2021). Thus, there is a need for context-specific communication strategies that address the relevant drivers and concerns in each setting.

Similarly, studies have shown that providing factual information about environmental and resource recovery benefits, together with a balanced presentation of all available options and a value-focused approach, can increase stated preference, even among individuals initially unfamiliar with technologies such as dry toilets (Aubert et al., 2022). However, empirical research on actual behavioural change in water conservation shows that knowledge and information alone rarely lead to lasting behavioural change, as long-term change is best achieved through a combination of behavioural influencing tactics targeting reflective, semi-reflective, and automatic processes, such as self-efficacy, social norms, framing, emotional cues, and nudges (Koop et al., 2019).

3.2.2. Factors influencing acceptance and WTP

The ordinal logistic regression analysis identified statistically significant relationships between certain independent variables and the dependent variables (Table 2). Environmental awareness was consistently positively associated with all dependent variables, general acceptance ($p < 0.001$), water acceptance ($p = 0.006$), WTP general ($p < 0.001$), and WTP maintenance ($p < 0.001$). The magnitude of the coefficients also suggest that greater environmental awareness is strongly linked to higher acceptance levels and WTP. In contrast, other factors showed significance only in specific cases and had z-values close to 2. The observed statistically significant associations are living arrangement with general acceptance ($p = 0.035$), environmental knowledge with general acceptance ($p = 0.038$), gender with water

acceptance ($p = 0.025$), and dwelling size with WTP maintenance ($p = 0.040$). Variables including age, education, income, area type, monthly rental costs, household size, professional sector, technological interest, and environmental experience, did not exhibit any statistically significant associations with the dependent variables. Full statistical results, including β, SE, z- and p-values, can be found in Table 2.

These findings are consistent with previous studies that also identified environmental awareness as a significant predictor of acceptance of and WTP (Kastner & Bobeth, 2018; Khan et al., 2020; Pierce et al., 2021; Zhang et al., 2018), as well as gender and knowledge in some cases (Dolnicar et al., 2011; Khan et al., 2020; Pierce et al., 2021; Portman et al., 2022). Interestingly, this study also found significant effects for dwelling size and living arrangement, two factors that have been less commonly investigated in similar research. This suggest that household structure and spatial conditions may play a more important role than previously assumed. In addition, Simha et al. (2021) found that acceptance of urine recycling varies strongly between countries and is shaped less by demographics but more by cognitive and cultural factors such as perceived benefits, social norms, and national context.

Another aspect, not yet investigated in our present study, is the effect of ownership. In our study, all respondents in the unaffiliated group were tenants. However, previous studies have shown that both home-ownership (Grant et al., 2020; Karytsas et al., 2019) and (co-)ownership of the technology itself (Roth et al., 2023) can positively influence acceptance and willingness to invest in such solutions. However, beyond legal ownership, the concept of psychological ownership has also been shown to play a role. Participation in community-based water projects can foster a sense of ownership, which in turn increases responsibility, care for shared infrastructure and willingness to pay (Ambuehl et al., 2022; Cecilia et al., 2024). In a related context, Preston & Gelman (2020) found that psychological ownership increases willingness to protect natural resources even more than legal ownership.

3.3. Preferences in organisation of maintenance

This section presents and discusses the results from the unaffiliated group related to preferences for organising maintenance within circular water systems. Such systems involve maintenance tasks that are directly

Table 2

Coefficients (β), standard errors (SE), z-values, and p-values from ordinal logistic regression models examining the relationship between independent and dependent variables. Asterisks indicate levels of statistical significance: *p < 0.05, **p < 0.01, ***p < 0.001.

Dependent variables	General acceptance				Water acceptance				WTP general				WTP maintenance			
Number of observations	271				271				247				236			
Independent variables	β	SE	z	p	β	SE	z	p	β	SE	z	p	β	SE	z	p
Age	0.023	0.138	0.164	0.870	-0.048	0.151	-0.321	0.748	0.082	0.143	0.570	0.568	-0.178	0.148	-1.202	0.229
Gender	-0.447	0.249	-1.794	0.073	-0.637	0.285	-2.240	0.025*	-0.029	0.271	-0.106	0.915	-0.180	0.278	-0.649	0.517
Professional sector	0.031	0.023	1.354	0.176	0.047	0.025	1.902	0.057	0.028	0.024	1.160	0.246	0.034	0.025	1.378	0.168
Level of education	0.148	0.132	1.120	0.263	-0.098	0.144	-0.677	0.499	0.278	0.142	1.958	0.050	-0.030	0.146	-0.207	0.836
Income	-0.097	0.140	-0.693	0.488	0.077	0.149	0.516	0.606	0.050	0.146	0.342	0.732	-0.022	0.144	-0.151	0.880
Monthly rental costs	-0.260	0.140	-1.858	0.063	-0.014	0.153	-0.092	0.926	1.0E-04	0.165	0.001	0.999	0.034	0.175	0.196	0.845
Dwelling size (area)	0.099	0.139	0.710	0.477	-0.067	0.143	-0.467	0.641	0.266	0.155	1.717	0.086	0.313	0.153	2.050	0.040*
Living arrangement	0.310	0.147	2.107	0.035*	0.291	0.162	1.793	0.073	0.177	0.156	1.139	0.255	0.205	0.158	1.299	0.194
Household size (persons)	0.110	0.136	0.809	0.419	0.047	0.143	0.327	0.744	-0.119	0.146	-0.816	0.414	-0.155	0.146	-1.059	0.290
Area type	0.101	0.129	0.783	0.434	0.131	0.141	0.926	0.355	0.057	0.141	0.401	0.688	0.103	0.146	0.707	0.480
Environmental awareness	0.724	0.126	5.755	9E-09***	0.371	0.134	2.770	0.006**	0.760	0.145	5.246	2E-07***	0.472	0.141	3.354	8E-04***
Environmental experience	0.090	0.125	0.717	0.473	0.053	0.132	0.403	0.687	0.011	0.127	0.084	0.933	-0.158	0.130	-1.219	0.223
Environmental knowledge	0.252	0.122	2.074	0.038*	0.132	0.133	0.998	0.318	0.059	0.132	0.448	0.654	0.039	0.133	0.290	0.772
Technological interest	0.162	0.125	1.295	0.195	0.091	0.134	0.676	0.499	-0.064	0.137	-0.465	0.642	0.217	0.139	1.564	0.118

or indirectly linked to the water cycle, raising questions about their optimal organisation. We explored user involvement in maintenance versus outsourcing these tasks and, for the latter, investigated respondents' willingness to pay for such services. Additionally, we aimed to identify factors that might motivate user involvement in maintenance.

3.3.1. Willingness to personally engage

Fig. 3 displays summary statistics for preferences towards three specific maintenance tasks: (1) gardening, weeding, and harvesting, (2) managing compost from toilets and recycling urine, and (3) conducting minor technical maintenance and inspections. Approximately half of the respondents were willing to personally undertake gardening (46.6 %) and technical maintenance (49.8 %). In contrast, the majority (76.8 %) preferred to outsource the management of composting toilets. These results somewhat contrast the findings of Aubert et al. (2022) where young Swiss citizens ranked user convenience factors, including technical maintenance and inspections, among the lowest priorities compared to other objectives. This difference could be attributed to age-related shifts in priorities, with older respondents potentially placing greater importance on ease of maintenance, to varying levels of information the survey respondents were exposed to, or to the influence of the trade-off methodology applied, which required assigning relative importance among competing objectives.

However, effective engagement and maintenance not only depend on users' willingness but also on structured organisational models and, to some extent, capable and reliable users. In addition, it is unclear whether such willingness will lead to actual participation. Bridging the gap between willingness and action requires a better understanding of behavioural incentives and support mechanisms that can sustain long-term engagement.

3.3.2. Drivers for personal engagement

Fig. 4 presents the results of a follow-up question posed to the respondents who initially indicated a preference for outsourcing specific maintenance tasks. For each task they preferred to outsource, respondents were asked what conditions would need to be in place for them to personally engage in it. These conditions represent potential drivers for engagement and included saving on costs, low level of effort required, no hygienic risks, fair task distribution among residents, and the availability of professional support. These factors were not further described in the survey and may therefore have been interpreted differently by respondents. The importance of these factors varied by task. For instance, ensuring hygiene was named crucial in the maintenance of compost toilets, likely due to health concerns associated with handling faeces. For gardening tasks, fair distribution and manageable effort levels were reported as the most important factors. In the case of technical maintenance, the availability of professional support was named most.

In Section 3.3.3, we found that respondents' willingness to pay for outsourcing maintenance was generally below the actual costs. While additional costs can therefore be regarded as a barrier, cost savings do not appear to be a primary driver for personal engagement (Fig. 4). Therefore, addressing organisational barriers to encourage greater user participation may offer a strategy to overcome the cost barrier, as users may not expect financial compensation equivalent to the full cost of outsourcing.

Having users participate in maintenance could be a viable approach for housing cooperatives, as seen in Switzerland and Uruguay, both high-income countries. These cooperatives emphasise collective decision-making, long-term affordability, and social cohesion (Balmer & Gerber, 2018; Barenstein et al., 2022). In Uruguay, certain cooperative models involve members directly in construction and maintenance, leading to a strong sense of ownership. Swiss cooperatives typically outsource maintenance but promote participatory governance (Barenstein et al., 2022). Meanwhile, community gardening is an
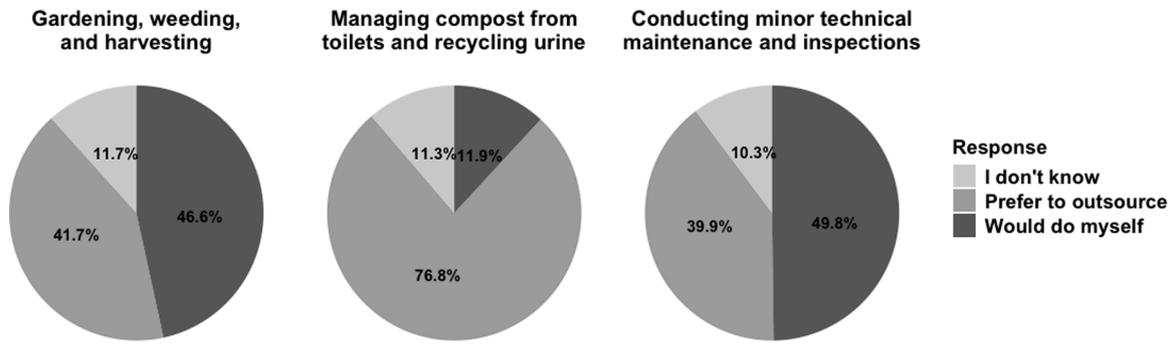
Fig. 3. Preferences of unaffiliated group for personal engagement versus outsourcing of maintenance tasks which are directly and indirectly related to circular water systems (n = 496).
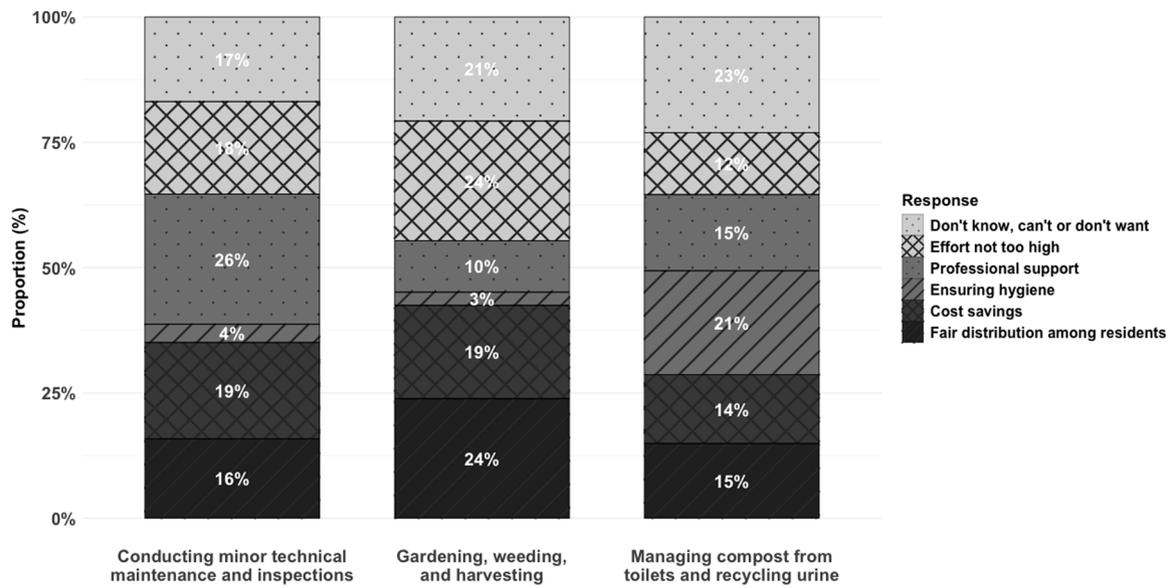

Fig. 4. Drivers for engaging in maintenance of unaffiliated group. Answers to the question: "From your point of view, what would it take for you to do gardening, weeding and harvesting / conduct minor technical maintenance and inspections / managing compost from toilets and recycling urine" (n = 425).
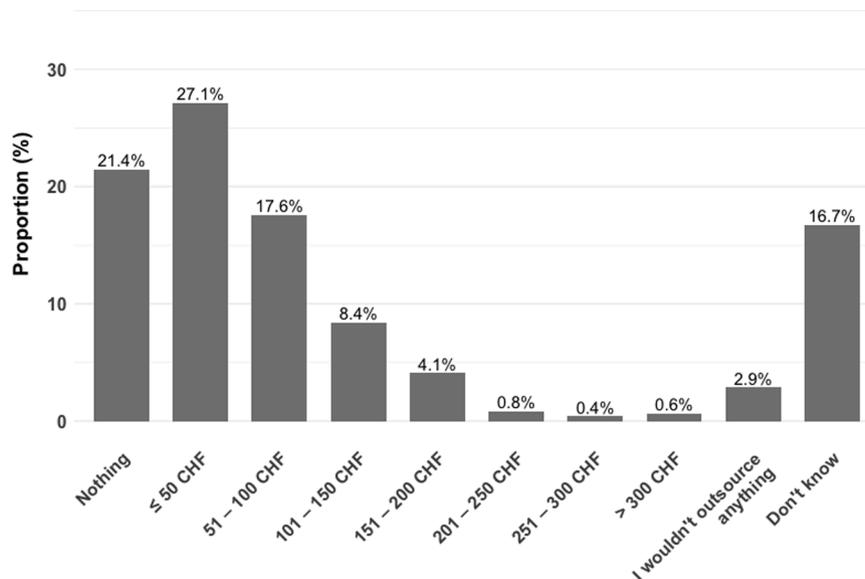

Fig. 5. Willingness to pay of unaffiliated group for outsourcing maintenance tasks. Answers to the question "How much more per month would you be willing to pay for the tasks you would prefer to outsource? (Total amount in CHF for all selected tasks to be outsourced)" (n = 490).

emerging urban trend, increasingly supported by policymakers and urban planners as part of broader sustainability strategies (Jahrl et al., 2022). Given these developments, communal cooperative structures could serve as a foundation and entry point for integrating user participation in circular water systems.

3.3.3. Preference for outsourcing

In terms of WTP for outsourced maintenance tasks, referring to the same tasks as in section 3.3.1, 60 % of respondents expressed a general willingness to pay, with the majority preferring to contribute up to 50 CHF per month (27.1 %) (Fig. 5). In contrast, 21.4 % were unwilling to pay anything, and 2.9 % indicated they would not outsource any tasks. Buehler et al. (2025a) estimated the maintenance costs for the water system in KREIS-Haus at CHF 108 per month, excluding expenses for dry toilet management and gardening. This suggests that the majority of respondents would not cover the full maintenance costs based on their stated willingness to pay. However, these costs could potentially be reduced in larger developments due to scaling effects. Building on this, future studies should assess maintenance costs for larger-scale applications, taking into account different system configurations, number of units served, degree of automation, service models, and local labour costs.

Outsourcing will only be feasible if specialised professional maintenance services tailored to circular water systems are available. Such service providers could be established through public-private partnerships (PPPs), a model that has long supported infrastructure development in the water sector by attracting private investment and helping local governments navigate economic, political, and technical challenges (Shambaugh & Joshi, 2021). Although circular water systems typically require smaller, decentralized investments, the cumulative need for oversight and regulatory enforcement can presents a barrier. In this context, PPPs could offer a mechanism to overcome both regulatory and cost-related challenges. A PPP model for circular water systems could involve a private company taking responsibility for system design, installation, and maintenance, while the public sector contributes funding, regulatory frameworks, and oversight. Residents or building owners would pay a service fee, and performance-based contracts would help ensure compliance with environmental and health standards.

Policy incentives such as tax benefits or cost-sharing schemes could further ease financial barriers. At the same time, clear regulations must define maintenance responsibilities, service quality, and hygiene protocols. Finally, from a technical and organisational perspective, innovations that simplify maintenance could reduce the burden on both users and service providers alike.

3.4. Impact of direct experience

This section presents the results of the comparative analysis between the affiliated group and unaffiliated subset.

3.4.1. Effects on acceptance and WTP

Fig. 6 outlines differences in both groups regarding acceptance and willingness to financially support sustainable building practices and circular water systems. The affiliated group exhibited a higher general acceptance of sustainable technologies compared to the unaffiliated subset, as indicated by a highly significant p-value (p < 0.001, W =
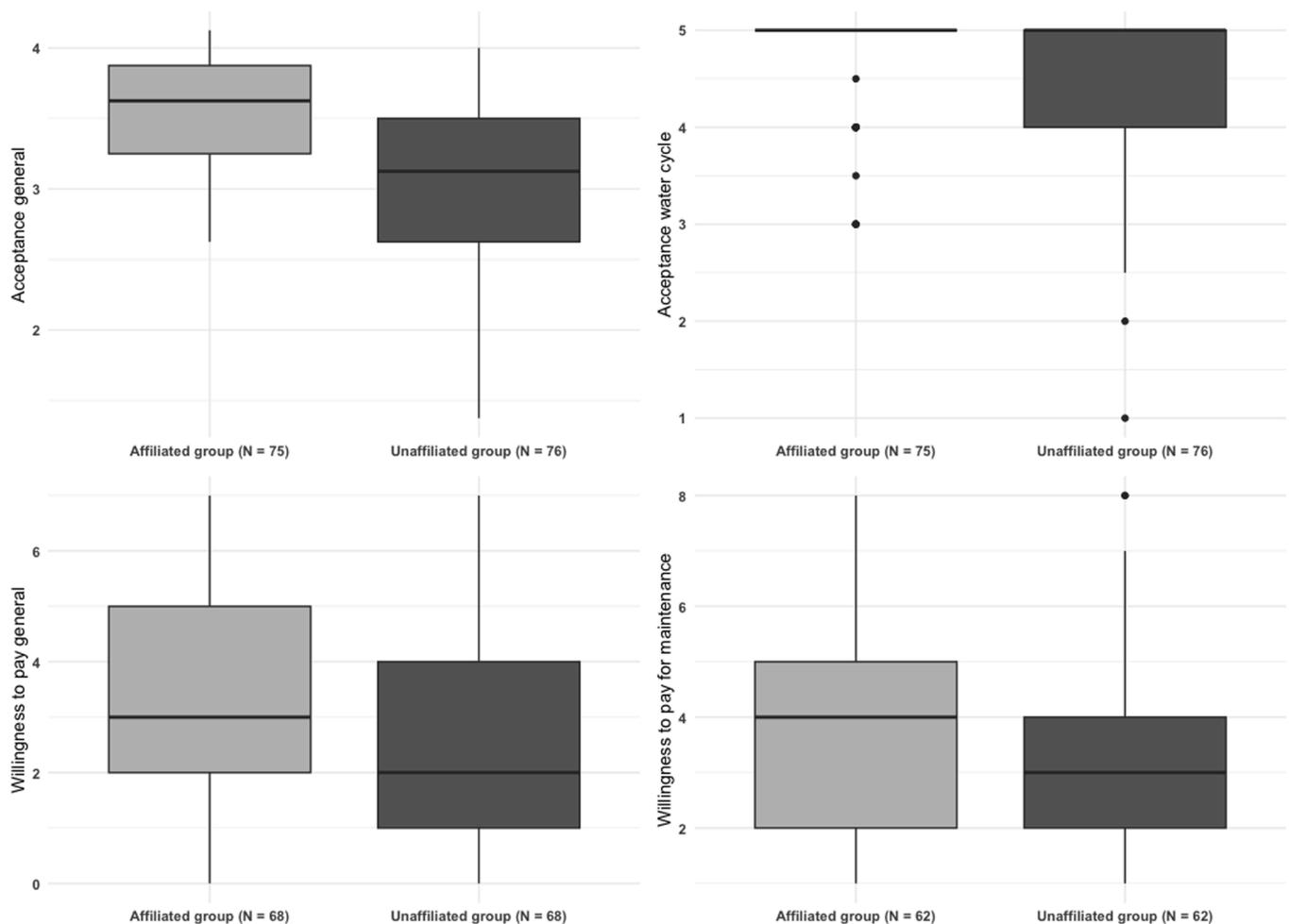

Fig. 6. Comparison of acceptance and willingness to pay between respondents who visited 'Affiliated group' and did not visit KREIS-Haus 'Unaffiliated group'.

1436). This suggests that direct exposure to these technologies may enhance overall openness to sustainable practices. Importantly, both groups were matched on environmental characteristics, indicating that the observed differences are not attributable to differences in initial environmental conditions. When looking specifically at the acceptance of circular water systems, the difference between both groups was also statistically significant (p = 0.018, W = 2327), however, acceptance of water cycle technologies was high in both groups. The strong difference in general acceptance is largely explained by the affiliated group's greater acceptance, or the unaffiliated group's stronger aversion, toward dry toilets and the practice of recycling human faeces for fertiliser, both of which are included in the general acceptance category. Qualitative feedback supports this finding, as many visitors initially expressed reluctance towards the dry toilet but reported being pleasantly surprised after being "obliged" to use it during their stay.

Direct experience also appears to play a role in influencing financial willingness to support sustainable practices. The affiliated group was more willing to pay general monthly extra living costs for sustainable buildings (p = 0.005, W = 1677) and for outsourced maintenance related to sustainable practices, including those for a closed water cycle (p = 0.005, W = 1366). These results suggest that experiential learning environments, like KREIS-Haus, may contribute to increased financial support for sustainable living.

Taking into account the demographic and socio-economic differences between the two groups (Table 1), it is possible that factors beyond the direct experience at KREIS-Haus influenced the higher acceptance and WTP observed in the affiliated group. While the samples were matched on environmental characteristics, differences in level of education, monthly rental costs, area type, living arrangement and professional sector remain (see Suppl. Material, Table S4). Interestingly, although the affiliated group had a much higher proportion of individuals with university degrees, their income and rent expenditures were not above the average. From this perspective, visitors to KREIS-Haus could be described as urban, highly educated individuals who appear to prioritise environmental concerns and a simpler lifestyle over material aspects.

3.4.2. Potential behavioural change through direct experience

In this study, we also examined the role of prior experience with sustainable technologies in shaping acceptance and WTP. Specifically, we assessed whether prior experience with individual measures, such as using photovoltaic systems, growing vegetables, or collecting rainwater, influenced acceptance and WTP. However, the regression analysis indicated that such prior environmental experience was not a strong predictor of higher acceptance or WTP in the unaffiliated group (Table 2, section 3.2.2). This suggests that the experience in the KREIS-Haus was a more influential driver, likely due to its integrated, hands-on demonstration and contextual explanations, compared to isolated use of single technologies in everyday life.

The positive impact of direct experience was also found in other studies. Tomic et al. (2020) demonstrated that experiencing low-flow showerheads in a public swimming pool significantly increased willingness to purchase them. Similarly, Brückmann (2022) found that test-driving a battery electric vehicle increased purchase intention by 11 %, whereas providing information alone had no effect. Such positive effect of direct experience can also be linked to the behavioural influencing tactics framework (Koop et al., 2019), in terms of its ability to simultaneously engage multiple behavioural pathways. Direct experience can support reflective processes by increasing knowledge and self-efficacy, semi-reflective processes through framing and tailoring, and potentially even automatic responses by evoking emotions, or through mechanisms such as priming and nudging. This highlights the value of real-life demonstration contexts to facilitate actual behavioural shifts. However, to what extent such shifts actually occur in the affiliated group after their stay would need to be further assessed, such as with both pre- and post-surveys.

4. Conclusions

This study examined user preferences, acceptance, and willingness to pay for circular water systems, focusing on maintenance organisation and the role of direct experience in a high-income context. It highlights key challenges and opportunities for broader implementation:

- Environmental awareness consistently emerged as the strongest predictor for acceptance and WTP. Less-studied factors, i.e. dwelling size and living arrangement, were also influential. The findings suggest that strategies tailored to both individual characteristics and broader socio-economic contexts could enhance acceptance.
- Experiential learning, as visitors experience in the KREIS-Haus, appears to be a powerful tool in promoting sustainable living as it simultaneously engages multiple behavioural pathways. Real-world demonstration spaces should be expanded beyond pilot projects and embedded in broader policy frameworks.
- Maintenance engagement is influenced more by hygiene concerns, fairness, and perceived effort than by cost. About half of respondents were willing to engage in gardening and basic technical maintenance, while most preferred to outsource toilet management. Cooperative housing models could support resident involvement, while PPPs could enable professional service models.
- Future research should explore the role of ownership models, both legal and psychological, in high-income contexts, as well as behavioural incentives to bridge the gap between willingness and action.
- Methodologically, this study offers a screening tool for deeper valuation studies. Future work should apply methods such as contingent valuation or discrete choice experiments and use incentive-compatible designs to mitigate bias.

Overall, this study offers actionable insights for improving the design, governance, and dissemination of decentralised circular water systems in urbanised, high-income settings.

CRediT authorship contribution statement

Devi Buehler: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Laila Luethi:** Writing – original draft, Methodology, Investigation, Formal analysis. **Diederik P.L. Rousseau:** Writing – review & editing, Supervision. **Alice H. Aubert:** Writing – review & editing. **Martina Bozzola:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.wroa.2025.100416.

Data availability

Data will be made available on request.

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