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Evaluating the effect of green, blue, and gray measures for climate change adaptation on children's well-being in schoolyards in Barcelona

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HIGHLIGHTS

- The study evaluates the effect of heat-adapted schoolyards on children's health.
- Students and teachers' perceptions were assessed using a mixed-method evaluation.
- The interventions improved schoolyard appreciation, heat perception, and comfort.
- Shaded and seating areas enhanced egalitarian relations and play opportunities.
- Urban strategies for climate change resilience should be expanded to other schools.

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ABSTRACT

Eleven primary schools in Barcelona were adapted to cope with the effects of climate change under the framework of a European program. Green (vegetation), blue (fountains), and gray (shade structures) interventions were implemented in the schoolyards in 2020. The objective of this study was to assess the impact of these schoolyard transformations on students' health and its social determinants. A mixed-methods evaluation was conducted: (1) a quantitative pre-post quasi-experimental study using self-reported questionnaires administered to all sixth-grade students from 21 schools (11 from an intervention group and 10 from a comparison group); and (2) a qualitative evaluation through photovoice-based sessions with 11- to 12-year-old students and interviews with teachers from the intervention group. We measured changes in perceptions of the schoolyard environment, play and social behavior, and students' health and well-being. Data were analyzed using a difference-in-differences approach for quantitative data and a thematic content analysis for qualitative data. After the intervention, both students' and teachers' perceptions of the schoolyard environment improved. They reported a decrease in heat sensation and an enhancement in schoolyard attractiveness and naturalization. Additionally, qualitative results suggest that the interventions promoted play opportunities and social inclusion, while reducing conflict behavior. Post-intervention, students also reported increased feelings of relaxation, safety, and physical comfort in the schoolyard. Our findings suggest the effects of the interventions may differ by gender. We identified potential areas for improvement in terms of cooling capacity, safety, water saving, and students' autonomy. This study supports the need to extend climate adaptations to other schools.

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1. Introduction

1.1. Climate change, urban health, and children

Climate change has become a major public health concern, with rising temperatures leading to increased premature deaths and various health problems, including cardiovascular, respiratory, and mental health conditions (Gasparrini et al., 2015; Marí-Dell'Olmo et al., 2019, 2022; Romanello et al., 2022). Urban areas are particularly vulnerable to these temperature increases due to urban heat islands (Ward et al., 2016), especially in warm and densely populated cities like those in the Mediterranean region (Marí-Dell'Olmo et al., 2019).

Children are especially sensitive and vulnerable to climate-related hazards such as extreme temperature (Antoniadis et al., 2020; Helldén et al., 2021; Xu et al., 2012). They experience high heat stress during breaks in traditional urban schoolyards, which are often characterized by hard surfaces, the absence of shading structures, and a general lack of vegetation (Antoniadis et al., 2020).

1.2. Theoretical framework

Several conceptual frameworks and prior research support the incorporation of green spaces, water features, and shade structures in schoolyards to improve heat resilience, defined as "the capability of the built environment to support outdoor activities during heat stress conditions" (Sharifi & Boland, 2017). Firstly, structures such as canopies or pergolas and planting trees can create cooler environments by providing shade that blocks solar radiation (Antoniadis et al., 2020; Stevenson et al., 2020; van den Bogerd et al., 2023). Secondly, vegetation can facilitate cooling through evapotranspiration and reduce indoor and outdoor air pollution in schools (Hartig et al., 2014; Markevych et al., 2017; van den Bogerd et al., 2023; van den Bogerd & Maas, 2024; van den Bosch & Ode Sang, 2017). Thirdly, easy access to drinking water can help children stay hydrated during play and regulate their body temperature (Kennedy et al., 2021).

The potential benefits of heat-adapted schoolyards extend beyond thermal comfort (Stevenson et al., 2020; van den Bogerd et al., 2023). Theories such as Stress Recovery Theory (Ulrich et al., 1991) and Attention Restoration Theory (Kaplan, 1995) suggest that exposure to nature can reduce stress and mental fatigue and enhance focus and cognitive function. The Biophilia Hypothesis (Kellert & Wilson, 1995) posits that green and blue spaces meet the innate human need to connect with nature, promoting psychological well-being and pro-social behavior in children (Collado et al., 2013). According to Affordance Theory (Gibson, 1979), natural play spaces offer a rich variety of affordances (i.e., the resources or support that the environment offers an individual), providing opportunities for a variety of play experiences and promoting open-ended, sensory, unstructured play. This, in turn, can potentially enhance physical activity (PA) and encourage the development of children's social and cognitive skills (Hartig et al., 2014; Markevych et al., 2017; van den Bogerd et al., 2023; van den Bogerd & Maas, 2024). In addition, higher ambient temperatures have been linked to sedentary behavior (Koepp et al., 2023), while heat, dehydration, and fatigue can increase aggression and irritability (Vanos, 2015). Thus, improving thermal comfort in schoolyards may encourage students to be more active and enhance their socio-emotional well-being.

1.3. Empirical research: Cooling and naturalizing schoolyards

Empirical evidence supports the idea that increasing shade coverage in schoolyards may improve thermal comfort. Recent studies have shown that shaded areas (whether natural or artificial) in these areas effectively lower temperatures (Vanos et al., 2016) and provide greater thermal comfort (Lanza et al., 2021a; Vanos et al., 2017) than in unshaded areas. Heat stress was found to be consistently reduced by the addition of natural and artificial shade to playgrounds (Huang et al., 2016), while higher temperatures were associated with increased time spent under shade during recess (Lanza et al., 2022). In addition, installing shade sails in several secondary schoolyards was considered valuable for cooling on hot days and their use was increased with the presence of tables and seats (Dobbinson et al., 2014).

Few empirical studies have evaluated the effect of school greening on children's well-being, attitudes, and behavior. However, existing studies suggest several positive outcomes associated with green schoolyards. These include enhanced schoolyard appreciation among students (van Dijk-Wesselius et al., 2018), perceived restorativeness (Akpinar, 2016; Bagot et al., 2015; van Dijk-Wesselius et al., 2018), greater diversity of play (Dyment & Bell, 2008a; Mårtensson et al., 2014; Raney et al., 2023; van Dijk-Wesselius et al., 2022), improved social behavior (Bates et al., 2018, Bohnert et al., 2022; Dyment & Bell, 2008b; Harper et al., 2021; Raney et al., 2019), and enhanced perceived safety (Bates et al., 2018). The findings on PA have been mixed, but some studies have reported a positive association (Bates et al., 2018; Dyment & Bell, 2007, 2008a; Lanza et al., 2022; Raney et al., 2019, 2023; van Dijk-Wesselius et al., 2018; Wood et al., 2014). Reports of the benefits of schoolyard greening have also been mixed, with several studies reporting greater benefits among girls (van Dijk-Wesselius et al., 2018, 2022; Raney et al., 2019; Wood et al., 2014), while others have suggested a more restorative effect among boys (Akpinar, 2016). The effect of implementing water features such as fountains in schoolyards on children's well-being, thermal comfort, and behavior remains understudied.

1.4. The "Climate shelters in schools" project

As part of the Urban Innovative Actions of the European Commission program, the city of Barcelona, Spain, initiated an innovative pilot project called "Climate shelters in schools". The project involved 11 primary schools, which were adapted to mitigate the effects of climate change. Through a co-creation process with the school communities, various measures were implemented to reduce heat in the schoolyards. These measures included a combination of green, blue, and gray elements tailored to each school's specific needs. Green elements involved planting trees, climbing plants, and Mediterranean garden species, as well as replacing hard surfaces with natural components. Blue elements comprised the installation of fountains for drinking, cooling, and playing purposes, while gray components, such as pergolas, canopies, and seating areas, were added to provide shade and comfort. These changes transformed the schoolyards: 1000 m^2 of concrete were replaced with natural components, 2213 m^2 of shade were created using pergolas and canopies, 74 trees were planted, and 26 new water sources were installed. Further details of the interventions have been published elsewhere (Ajuntament de Barcelona, 2020; Ecology, Urban Planning, Infrastructures and Mobility, n.d.; Plazas et al., 2023).

1.5. The present research and hypotheses

It is essential to evaluate the health impact of urban programs, including innovative interventions, to assess their effectiveness and identify areas for improvement. Current research lacks a comprehensive understanding of how combining green, blue, and gray solutions affect children's thermal comfort, playability, social behavior, physical health, and mental well-being. Specifically, there is a dearth of studies employing mixed methodologies (quantitative and qualitative), utilizing pre-post designs, and examining multiple outcomes simultaneously. These approaches would offer a more holistic view of the impact of interventions and provide stronger evidence. Moreover, to our knowledge, no studies have evaluated such impacts in Mediterranean primary school settings.

Building upon existing theoretical frameworks and prior empirical research, we developed a conceptual framework to evaluate the "Climate shelters in schools" project. This conceptual framework was used to guide our assessment of these interventions to enhance

children's perceptions of the schoolyard environment, play and social behavior, and their health and well-being outcomes (Sanz-Mas et al., 2024). The present study is focused on the effects of schoolyard transformations on schoolchildren's health and its social determinants. We measured changes in students' and teachers' perceptions of the schoolyard environment, play and social behavior, and well-being. We hypothesized that the intervention would significantly improve these perceptions and promote play opportunities, PA, and positive social behavior among students, thereby enhancing their overall health and well-being, with more notable improvements in the intervention group (IG) than in the comparison group (CG).

2. Materials and methods

We conducted a mixed-method evaluation that included a quantitative pre-post quasi-experimental design and a qualitative assessment. The study population comprised 11- to 12-year-old sixth-grade students, as classified by the Spanish educational system, and teachers from public primary schools in Barcelona. Eleven schools were selected for interventions (IG) based on criteria such as greater vulnerability to climate change and increased social complexity, while ensuring representation from all city districts. A climate change vulnerability score was developed considering potential intervention's impact, school environment, school building conditions, and schoolyard characteristics. Schools with higher scores were prioritized. If schools from the same district received tied scores, those with higher school complexity, determined by factors such as families' level of studies, employment situation, income, and student special needs, were given preference. For detailed school selection criteria, please refer to the published study protocol (Sanz-Mas et al., 2024). Ten additional schools formed the CG. These schools, which applied to participate in the project but were not selected for intervention, had similar characteristics to those in the IG based on eligibility criteria.

The physical transformation of the schoolyards took place between July and August 2020. Data collection was conducted at participating schools in November 2020 and May 2021. We analyzed quantitative and qualitative data separately and then converged the results using a concurrent mixed-method triangulation design (Bryman, 2006; Creswell and Clark, 2017).

2.1. Quantitative pre-post quasi-experimental evaluation

The sample consisted of all sixth-grade students (11–12 years old) from 11 schools in the IG and 10 schools in the CG. IG students participated in the co-creation process of selected interventions during the 2019–2020 school year. Both groups were administered online questionnaires during school hours at two different times. Due to school closures before and during the interventions as a COVID-19 measure, we obtained pre-intervention data retrospectively in November 2020. Post-intervention data were collected 9 months after the interventions, in May 2021. A total of 851 students (447 in the IG and 404 in the CG) participated in the evaluation. However, 792 students (407 in the IG and 385 in the CG) participated in both the first and second assessments and were included in the analysis.

We designed self-reported questionnaires based on previously validated (Andersson et al., 1998; Ravens-Sieberer et al., 2014) and reliable

Table 1
Dimensions and subdimensions, questions, and sources of the student's questionnaire.

Dimensions and subdimensions	Questions	Source
Perception of schoolyard environment		
Schoolyard likability (from 1 to 10)	"Rate the likability of your schoolyard on a scale from 1 to 10 (from 1 = "I do not like my schoolyard at all" to 10 = "My schoolyard is fantastic")"	van Dijk-Wesselius et al., 2018
Schoolyard affinity (from 1 = low affinity to 5 = high affinity)	Grade of agreement (from 1 = strongly disagree to 5 = strongly agree) on the following questions: "The schoolyard is the best place to have fun", "I think the schoolyard is a good place to be comfortable", "I like the schoolyard as it is now."	Collado Salas, 2012
Perception of green spaces (very good/good)	"What do you think about areas with plants and green open space?"	Andersson et al., 1998
Perception of seating areas (very good/good)	"What do you think about places to sit?"	
Perception of shaded areas (very good/good)	"What do you think about shaded areas?"	
Play and social behavior		
Perception of play opportunities	"What do you think about possibility for activities?"	Andersson et al., 1998
Type of activity	"Which of the following activities do you usually do in the schoolyard"? We categorized them as sports (football, basketball, others), non-sport games (chasing games, singing, dancing, running, jumping, climbing, building, others), non-play behavior (talking, viewing others' games)	Play Activities in the Schoolyard (Van Dijk-Wesselius et al., 2018)
Physical activity	"What do you usually do in the schoolyard?" (run, walk, or sit)	
Social play	"How do you usually play in the schoolyard?" (alone, with one or two peers, with three or more peers)	
Mixed-gendered play	"Who do you usually play with in the schoolyard?" (only boys, only girls, both)We created the variable "mixed-gendered play" (yes/no)	
Health and well-being		
Health-related quality of life (T-score), *KIDSCREEN-10 index*	"Have you felt fit and well?", "Have you felt full of energy?", "Have you felt sad?", "Have you felt lonely?", "Have you had fun with your friends?", "Have you had enough time for yourself?", "Have you been able to do the things that you want to do in your free time?", "Have your parent(s) treated you fairly?", "Have you got on well at school?", "Have you been able to pay attention?"	KIDSCREEN-27 (Ravens-Sieberer et al., 2014)
Physical well-being (T-score)	"In general, how would you say your health is?", "Have you felt fit and well?", "Have you been physically active (e.g., running, climbing, biking)?", "Have you been able to run well?", "Have you felt full of energy?"	
Psychological well-being (T-score)	"Has your life been enjoyable?", "Have you been in a good mood?", "Have you had fun?", "Have you felt sad?", "Have you felt so bad that you didn't want to do anything?", "Have you felt lonely?", "Have you been happy with the way you are?"	
School well-being (T-score)	"Have you been happy at school?", "Have you got on well at school?", "Have you been able to pay attention?", "Have you got along well with your teachers?",	
Self-perceived health (excellent or very good)	"In general, how would you say your health is?"	

measures (Collado Salas, 2012; van Dijk-Wesselius et al., 2018). The questionnaires included the following dimensions: (a) perceptions of the schoolyard environment, (b) play and social behavior, (c) health and well-being. Table 1 summarizes the dimensions and subdimensions of the students' questionnaire, the specific questions used for each subdimension, and the validated and reliable tools employed. Selection of the study dimensions and subdimensions was based on the theoretical framework and observed outcomes from similar prior empirical research (see the Introduction section).

We also collected sociodemographic data from the students, including sex (girl or boy), age, socioeconomic position (SEP) based on the family affluence scale (FAS) (Boyce et al., 2006), migration trajectory, and family structure (Currie et al., 2014). Based on the FAS index, family SEP was categorized as "low" (<7), "medium" (7–9), and "high" (>9). In addition, we considered the schools' neighborhood SEP, using data from the territorial distribution of family income per capita in Barcelona in 2017 (Ajuntament de Barcelona, 2017).

2.1.1. Perceptions of the schoolyard environment

Before and after the intervention, students rated the likability of their schoolyard on a scale from 1 to 10 (van Dijk-Wesselius et al., 2018) and their schoolyard affinity on a scale from 1 to 5 (Collado Salas, 2012), which captures appreciation of the schoolyard in terms of opportunities for fun, comfort, and general likability. Students were also asked about their perceptions of specific physical characteristics of their schoolyards, such as green spaces, seating areas, and shaded areas (Andersson et al., 1998). These variables were dichotomized as "very good/good" and "acceptable/poor/very poor".

2.1.2. Play and social behavior

First, students described their perceptions of the schoolyard in terms of play opportunities, which were categorized as "very good/good" or "acceptable/poor/very poor" (Andersson et al., 1998). Second, information was gathered on the types of activities students usually engaged in within the schoolyard (Van Dijk-Wesselius et al., 2018), categorizing them as sports, non-sport games, or non-play behavior. PA levels were determined by asking students to indicate if they usually ran, walked, or sat during recess (Van Dijk-Wesselius et al., 2018).

To understand students' social behavior, we gathered data about their social play, categorized as playing "alone", "with one or two peers", or "with three or more peers" (Van Dijk-Wesselius et al., 2018). In addition, students reported whether they played with "boys", "girls", or "both" (Van Dijk-Wesselius et al., 2018) and we created the variable "mixed-gender play" (yes/no).

2.1.3. Health and well-being

To evaluate students' health outcomes, we used the KIDSCREEN-27 instrument (Ravens-Sieberer et al., 2014), which assesses various dimensions of health. We evaluated health-related quality of life (using the KIDSCREEN-10 index), as well as physical, psychological, and school well-being. All KIDSCREEN items are rated on a five-point Likert scale based either on the frequency of occurrence (never, seldom, quite often, very often, always) or intensity of statement (not at all, slightly, moderately, very, extremely). Scores were expressed as T-scores, with a mean of 50 and a standard deviation of 10 (The KIDSCREEN Group Europe, 2006). Higher T-scores indicate better quality of life, physical, psychological, and school well-being.

Self-perceived health was also measured and was categorized as "excellent or very good" and "good, fair, or poor". Retrospective pre-intervention measures for any health outcome were not collected, as they are generic measures of children's well-being and could be influenced by various individual and contextual factors, including COVID-19. In addition, generic measures are generally more strongly affected by recall biases than specific indicators.

2.1.4. Data analysis

We performed a descriptive analysis of all variables, estimating percentages for categorical variables and calculating the means of pre- and post-assessment measures for continuous variables. Baseline measures between the IG and the CG were compared using the chi-square or Fisher exact tests for categorical variables and the *t*-test for continuous variables.

To assess changes between pre- and post-measures within groups, we used the McNemar test for categorical variables and the paired sample *t*-test for continuous variables. For each study outcome, we employed the difference-in-differences approach to compare pre-post changes between the IG and the CG. We built multilevel mixed-effects logistic regression models for categorical variables and linear regression models for continuous variables, which included the interaction term between intervention status (IG/CG) and period (pre/post).

To estimate the real effect of the intervention, we calculated average adjusted predictions with random intercepts and derived the average marginal effects of the intervention for each outcome (Williams, 2012). For health outcomes, only post-assessment data were available. Consequently, we built Poisson regression models with robust variances (adjusted prevalence ratio, aPR) and linear regression models (coefficient β), as appropriate, to compare post-assessment measurements between the IG and the CG. Analyses were stratified by sex and adjusted for the SEP of the school neighborhoods. All analyses were conducted using the statistical package STATA 15.1 (*StataCorp LLC., USA*).

2.2. Qualitative evaluation

2.2.1. Evaluating student perceptions of the effects of the intervention

We assessed students' perceptions using the photovoice methodology (Wang & Burris, 1997). Four schools from the IG were selected to participate based on the following criteria: (a) schools from districts with different SEPs, (b) schools undergoing various combinations of interventions, and (c) willingness of the school's head to participate in the evaluation. Convenience samples of sixth-grade students were chosen in each participating school, based on variability in terms of sex and friendship groups, as well as students' availability, willingness, and motivation to participate. Our goal was to recruit around 10 students per school to represent diverse opinions and enable an in-depth exploration of students' experiences and perceptions of the intervention (Nykiforuk et al., 2011). To accommodate a request made by one school, the group size was increased to 25 students in this school, resulting in a total of 59 participants. This sample size allowed us to reach data saturation.

We conducted three photovoice sessions, each lasting 60–90 min, in each school after the intervention (May 2021). In the first session, groups of two or three students were encouraged to take pictures of the interventions adopted by their school that they considered most and least useful to combat climate change. We received a total of 64 photographs. In the second session, students discussed their photographs (a maximum of two photos per group) with a larger group, using an adaptation of the SHOWED method (Strack et al., 2004). Photographs served as a powerful tool to facilitate students' articulation of their positive and negative subjective experiences and perceptions on the schoolyard interventions. This approach empowered students to express their opinions and contribute to the evaluation process. The students identified pictures that best reflected their opinions. In the final session, we asked students how the interventions had changed their use of the space, social interactions, and feelings about the schoolyard. The students captured their thoughts by writing and drawing murals.

2.2.2. Evaluating teachers' perceptions of the interventions and their effects

Eleven teachers from the IG (one from each school) were selected from those who had been involved in different stages of the project and had actively participated in the co-creation process. Ultimately, seven teachers engaged, while four did not participate due to high workload and lack of time. This sample size allowed us to reach data saturation

and capture diverse perspectives in different schools. It also enabled an in-depth exploration of teachers' perceptions and experiences of the interventions, while minimizing additional workload for school staff.

We conducted an online group interview, lasting approximately 90 min, with five of the seven teachers to gather their experiences and perceptions regarding the interventions and their impact on students' well-being. The interview was facilitated by a moderator who was assisted by an observer. We used semi-structured guides covering the following thematic areas: impact of the transformations on students' comfort and well-being (including the interventions that most and least benefited students), impact on play and behavior during recess (e.g., play and use of spaces, social behavior, and interaction among students), overall satisfaction, and additional thoughts. Two teachers could not attend the group meeting and were interviewed individually via video or telephone call following the same semi-structured guides.

2.2.3. Data analysis

Verbal reflections from student's photovoice sessions and teacher interviews were audio-recorded and transcribed. The transcripts were complemented by students' photographs and observers' field notes from teacher interviews. We conducted a thematic content analysis to identify common codes and topics related to the focus of the evaluation.

For the qualitative evaluation, we employed an inductive approach based on grounded theory, allowing themes and categories to emerge directly from the collected data. The coding frame was developed iteratively throughout the data analysis process. Initial codes were generated through open coding of the first transcripts, then refined and organized into a coherent structure as subsequent interviews and photovoice transcripts were analyzed. This ongoing process ensured that the coding frame remained grounded in the data. The minimum unit of analysis was defined as a sentence.

The coding process was performed by three members of the research team. The final codes and categories were agreed upon by all members of the research team. Three main categories emerged: (a) perceptions of the schoolyard environment; (b) play and social behavior; (c) health and well-being. A reflexivity statement was added to account for how the qualitative research process was shaped by subjective perspectives and the researchers' individual characteristics (see Supplement 1).

3. Results

3.1. Quantitative results

Table 2 shows the sociodemographic characteristics of the students included in the analysis. The IG and the CG were similar in terms of sex, age, SEP, migration trajectory, and family structure. However, differences were observed in the neighborhood SEP of the schools, which was significantly lower in the IG (low SEP: 30 %) than in the CG (low SEP: 5.2 %, $p < 0.001$).

Changes between pre- and post-intervention measures in the IG and the CG are shown in Supplementary Table S1 (girls) and S2 (boys). Before the interventions, schoolyard likability, schoolyard affinity, and perceptions of green spaces, shaded areas, and seating areas were poorer among the IG than in the CG in both sexes (p-values < 0.01). Similarly, perceptions of play opportunities were lower in the IG (girls: p-values $= 0.026$; boys: p-value $= 0.054$).

After the interventions, girls' schoolyard likability and affinity scores significantly increased in the IG, while worsening in the CG (p-values < 0.01). Boys in the IG showed a similar increase in schoolyard affinity scores (p-values < 0.01). Perceptions of green spaces, shaded areas, and seating areas improved among IG students (p-values < 0.05), whereas perceptions of green spaces, shaded areas, and play opportunities worsened among CG students (p-values < 0.05).

The percentage of students who reported they played sports during recess decreased in the IG, especially among boys (p-value $= 0.007$), while remaining similar in the CG. For both groups and sexes, non-sport games significantly decreased (p-values < 0.05). There was a statistically significant reduction in non-play behavior among IG boys (p-value $= 0.031$).

Analysis of PA levels showed that boys in the IG significantly increased their sitting time (p-value $= 0.007$) while boys in the CG increased their walking time (p-value $= 0.032$). A statistically significant decrease in running was found in boys in both groups and in girls in the CG (p-values < 0.05).

Table 3 compares pre-post intervention changes between the IG and CG. The results showed a significant increase in schoolyard likability in the IG versus the CG among both girls (+1.8, 95 %CI: 1.3 to 2.2) and boys (+1.0, 95 %CI: 0.6 to 1.5). Similarly, schoolyard affinity increased significantly in the IG among girls (+0.7, 95 %CI: 0.5 to 0.9) and boys (+0.6, 95 %CI: 0.4 to 0.8) in comparison with the CG. Perceptions of the schoolyard, including green spaces, shaded areas, and seating areas, also significantly improved in both sexes in the IG compared with the CG. Perceptions of play opportunities remained similar in the IG in both sexes, but worsened in the CG. Boys in the IG significantly decreased their participation in sports after the intervention compared with boys in the CG (−10.2 %, 95 %CI: −19.4 % to −1.0 %).

Table 4 describes the results for health and well-being outcomes, comparing post-intervention assessment measurements between the IG and the CG. Boys in the IG scored significantly higher than those in the CG in dimensions related to quality of life ($\beta = 3.09$, 95 %CI=1.14 to 5.04), physical ($\beta = 3.02$, 95 %CI=0.82 to 5.21) and school-related well-being ($\beta = 3.11$, 95 %CI=1.23 to 5.00). A similar trend, close to significance, was found for the psychological dimension ($\beta = 1.87$, 95 % CI=-0.17 to 3.91). No differences were found in outcomes related to health and well-being among girls between the IG and CG.

Table 2
Characteristics of the participants in the questionnaires. Barcelona, 2020–2021.

	IG (N=407)	CG (N=385)	
	n (%)	n (%)	p[1]
Student characteristics			
Sex			
Girl	182 (44.7)	185 (48.0)	0.347
Boy	225 (55.3)	200 (52.0)	
Age (years)			
Age [Mean (SD)]	11.3 (0.5)	11.4 (0.5)	0.246
Family characteristics			
Family SEP (Family affluence scale)			
Low	134 (32.9)	109 (28.3)	0.319
Medium	189 (46.5)	185 (48.1)	
High	84 (20.6)	91 (23.6)	
Migration trajectory			
Native child with native-born parents	210 (52.6)	218 (58.6)	0.247
Native child with foreign-born parents	145 (36.4)	119 (32.0)	
Foreign-born child	44 (11.0)	35 (9.4)	
Family structure			
Single parent	87 (21.4)	70 (18.2)	0.470[2]
Two-parent	282 (69.3)	284 (74.0)	
Stepparent	32 (7.8)	27 (7.0)	
Others	6 (1.5)	3 (0.8)	
School characteristics			
Neighborhood SEP			
Low	122 (30.0)	20 (5.2)	**<0.001**
Medium	260 (63.9)	292 (75.8)	
High	25 (6.1)	73 (19.0)	

CG: Comparison group; IG: intervention group; SD: Standard deviation; SEP: socioeconomic position

Note: Missing values < 5 %.

[1] χ^2-square test (categorical variables)/T-test (continuous variables). Bold = p-value < 0.05.

[2] Fisher's exact test.

3.2. Qualitative results

A total of 59 students participated in the photovoice sessions, which were divided into four groups of 10 to 25 children each. The percentage

Table 3
Percentual average marginal effect estimation of the intervention and comparison groups for students' perception of schoolyard environment and play and social behavior, and percentual difference in differences average marginal effect. Barcelona, 2020–2021.

	Girls			Boys		
	IG (N=182)	CG (N=185)	Diff-in-Diff	IG (N=225)	CG (N=200)	Diff-in-Diff
	% Dif. POST2-PRE[1] (95 % CI)	% Dif. POST2-PRE[1] (95 % CI)	% Dif. IG-CG[2] (95 % CI)	% Dif. POST2-PRE[1] (95 % CI)	% Dif. POST2-PRE[1] (95 % CI)	% Dif. IG-CG[2] (95 % CI)
Perception of schoolyard environment						
Likability score, M	**0.6 (0.2 to 0.9)**	**−1.1 (−1.5 to −0.8)**	**1.7 (1.2 to 2.2)**	−0.2 (−0.5 to 0.1)	**−1.2 (−1.5 to −0.8)**	**1.0 (0.5 to 1.4)**
Affinity score, M	**0.3 (0.2 to 0.5)**	**−0.4 (−0.5 to −0.2)**	**0.7 (0.5 to 0.9)**	**0.2 (0.1 to 0.3)**	**−0.4 (−0.5 to −0.2)**	**0.6 (0.4 to 0.8)**
Green spaces (very good/good)	**33.0 (24.8 to 41.2)**	**−11.0 (−20.1 to −1.8)**	**44.0 (31.7 to 56.3)**	**33.8 (25.7 to 41.8)**	**−17.2 (−26.4 to −8.0)**	**51.0 (38.8 to 63.2)**
Shaded areas (very good/good)	**14.9 (5.7 to 24.0)**	**−16.6 (−25.7 to −7.5)**	**31.5 (18.6 to 44.4)**	**10.3 (2.2 to 18.5)**	**−20.5 (−29.1 to −11.9)**	**30.8 (19.0 to 42.6)**
Seating areas (very good/good)	**23.4 (14.7 to 32.0)**	−3.3 (−11.7 to 5.0)	**26.7 (14.7 to 38.7)**	**24.4 (17.3 to 31.6)**	−5.2 (−13.3 to 2.9)	**29.6 (18.9 to 40.5)**
Play and social behavior						
Perception of play opportunities						
Play opportunities (very good/good)	−3.0 (−10.9 to 4.8)	**−19.4 (−27.8 to −11.1)**	**16.4 (4.9 to 27.9)**	−1.0 (−8.7 to 6.8)	**−16.6 (−25.1 to −8.0)**	**15.6 (4.1 to 27.1)**
Type of activities						
Sports	−8.2 (−16.9 to 0.5)	−2.2 (−10.8 to 6.5)	−6.0 (−18.3 to 6.2)	**−9.1 (−15.7 to −2.5)**	3.6 (−2.9 to 10.1)	**−12.7 (–22.0 to −3.4)**
Non-sport games	**−5.5 (−10.2 to −0.7)**	**−9.8 (−15.5 to −4.1)**	4.3 (−3.2 to 11.8)	**−10.3 (−15.4 to −5.2)**	**−6.5 (−11.8 to −1.1)**	−3.8 (−11.2 to 3.6)
Non-play behavior	−1.2 (−7.1 to 4.8)	4.6 (−0.7 to 9.9)	−5.8 (−13.7 to 2.2)	**−8.0 (−15.0 to −1.0)**	−6.0 (−12.7 to 0.8)	−2.0 (−11.8 to 7.7)
Physical activity						
Sitting	**7.2 (0.0 to 14.5)**	6.2 (−2.2 to 14.6)	−1.0 (−10.1 to 12.1)	**6.8 (2.1 to 11.4)**	2.5 (−3.3 to 8.3)	4.3 (−3.1 to 11.8)
Walking	−3.8 (−12.8 to 5.1)	3.8 (−4.8 to 12.3)	−7.6 (−20.1 to 4.8)	5.8 (−0.7 to 12.2)	**7.5 (0.7 to 14.3)**	−1.7 (−11.1 to 7.6)
Running	−3.9 (−12.4 to 4.6)	**−9.6 (−17.8 to −1.4)**	5.7 (−6.1 to 17.5)	**−12.4 (−19.1 to −5.7)**	**−10.1 (−17.5 to −2.7)**	−2.3 (−12.2 to 7.7)
Social play						
Playing alone	−1.2 (−3.7 to 1.4)	−2.1 (−4.7 to 0.5)	0.9 (−2.8 to 4.6)	−1.3 (−3.4 to 0.9)	−0.5 (−3.7 to 2.7)	−0.7 (−4.6 to 3.1)
With one or two peers	−3.3 (−11.9 to 5.2)	−2.7 (−10.7 to 5.4)	−0.6 (−12.4 to 11.1)	−3.7 (−9.4 to 1.9)	−4.7 (−9.7 to 0.3)	1.0 (−6.5 to 8.5)
With three or more peers	4.4 (−4.2 to 13.0)	4.3 (−3.8 to 12.4)	0.1 (−11.7 to 11.9)	5.1 (−0.6 to 10.7)	5.3 (−0.1 to 10.7)	−0.2 (−8.1 to 7.6)
Mixed-gender play						
Mixed-gender group	5.9 (−2.6 to 14.5)	**12.0 (3.3 to 20.7)**	−6.1 (−18.3 to 6.2)	6.2 (−1.7 to 14.0)	0.0 (−8.5 to 8.5)	6.2 (−5.4 to 17.7)

CG: Comparison group; CI: confidence interval; IG: intervention group; M: mean; pre: pre-intervention measures; post: post-intervention measures (May 2021).

[1] Percentage (%) or mean (M) difference of the average marginal effect estimates of the intervention or comparison group, with 95 % CI = %post − %pre or Mpost − Mpre. Bold = p-value < 0.05.

[2] Percentage difference in differences of the average marginal effect estimate between IG and CG=[(%post_IG − %pre_IG) − (%post_CG − %pre_CG)] or [(Mpost_IG − Mpre_IG) − (Mpost_CG − Mpre_CG)]. Bold = p-value < 0.05. Models were adjusted by school's neighborhood SEP.

Table 4
Lineal regression and Poisson regression (with robust variances) models for differences in post-intervention measures about health and well-being of students between intervention and comparison groups. Barcelona, 2021.

	Girls (N=367)			Boys (N=425)		
	post, M (SD)	β[1]	95 % CI	post, M (SD)	β[1]	95 % CI
Self-perceived health (excellent or very good)						
Intervention group, % (95 % CI)	75.3 (68.3 to 81.4)	1.02	0.90 to 1.15	76.4 (70.3 to 81.8)	1.02	0.90 to 1.14
Comparison group, % (95 % CI)	76.2 (69.4 to 82.2)	Ref.		74.5 (67.9 to 80.4)	Ref.	
Quality of life score						
Intervention group	47.9 (9.9)	0.40	−1.49 to 2.30	51.3 (10.1)	**3.09**	1.14 to 5.04
Comparison group	47.7 (7.1)	Ref.		48.5 (9.1)	Ref.	
Physical well-being score						
Intervention group	47.9 (9.8)	0.18	−1.84 to 2.19	52.0 (10.7)	**3.02**	0.82 to 5.21
Comparison group	48.2 (8.5)	Ref.		49.0 (11.0)	Ref.	
Psychological well-being score						
Intervention group	49.6 (10.8)	−0.04	−2.29 to 2.22	52.6 (10.5)	1.87	−0.17 to 3.91
Comparison group	50.2 (9.6)	Ref.		50.8 (9.6)	Ref.	
School-related well-being score						
Intervention group	51.9 (10.2)	1.41	−0.64 to 3.46	52.7 (9.0)	**3.11**	1.23 to 5.00
Comparison group	51.3 (8.6)	Ref.		49.8 (9.6)	Ref.	

CI: confidence interval; M: mean; Ref: Reference group; SD: standard deviation; post: measures from second post-assessment (May 2021).
Analyses were adjusted by school's neighborhood SEP. Bold associations with a p-value < 0.05.
[1] adjusted prevalence ratio (aPR) was calculated (through Poisson regression models with robust variances) for self-perceived health instead of β.

Table 5
Perceptions of the school community (students and teachers) regarding the effects of the interventions. Barcelona, 2021.

Categories	Codes	Intervention	Source
Perception of schoolyard environment	(+) Improving appreciation of the schoolyard	all	PV, I
	(+) More natural and attractive schoolyard	green	PV, I
	(+/−) Preference for mixed or green shaded areas	green, grey	PV
	(+) Reducing outdoor heat perception	all	PV, I
	(+) Enhancing air quality	green	PV
	(−) Not enough shade	green, grey	PV, I
	(−) Number, height, location, and others could be improved	all	PV, I
	(−) Potential waste of water	blue	PV, I
	(−) School rules	blue, grey	PV
	(−) COVID-19 restrictions	blue	PV, I
Play and social behavior	(+) Greater diversity of play areas and opportunities	all	PV, I
	(+) Football decentralization	green, grey	PV, I
	(+/−) Increasing quiet activities	green, grey	PV, I
	(−) Less engaging for some students	green, grey	PV, I
	(+) Enhancing pro-social behavior	green, grey	PV, I
	(+) Promoting mixed-gender interaction	green, grey	PV, I
	(−) School rules and COVID-19 restrictions	all	PV, I
Health and well-being	(+) Improving comfort at the schoolyard	green, grey	PV, I
	(+) Improving relaxing feelings	green, grey	PV, I
	(+) Improving safety perception	green, grey	PV, I
	(−) Safety issues	blue, green	PV

(+) positive aspects; (−) negative aspects; all: blue, green, and grey interventions; I: group/individual interviews (teachers); PV: photovoice (students).

of girls in the groups ranged from 30 % to 58 %. Examples of photographs taken and selected by students in each school are shown in Fig. S1 (see Supplementary data). Seven teachers participated in group or individual interviews and most were women (86 %). Table 5 provides a list of codes and categories from the qualitative evaluation.

3.2.1. Perceptions of schoolyard environment

Most students and teachers felt that the interventions had improved the schoolyards. They had a positive view of the new shaded areas, seating, and greenery. Students expressed a preference for green or mixed-type interventions, which made the schoolyards look more natural and appealing. Overall, students and teachers also reported feeling better in terms of heat sensation. They were satisfied with the planted vegetation, pergolas, and canopies because they provided shade and a cooling effect (e.g., *"More shaded areas were created and it's less hot."* student). Students also noticed that the vegetation improved air quality.

Despite the benefits of the shade measures, some participants identified areas requiring improvement in terms of thermal comfort. Firstly, most students and teachers agreed that there was still a shortage of vegetation or that it was insufficiently grown. As a result, the impact of the vegetation on temperature was hard to notice. In addition, teachers mentioned the lack of maintenance of the green areas.

> "Vegetation is still insufficiently grown, and there's not much difference in comparison with the pre-intervention period." (teacher)

Secondly, some teachers and students suggested increasing the number of canopies and installing them in the most heat-prone areas of the schoolyard, such as the sports court. Students also thought that the shade provided by the pergolas was inadequate, as sunlight was able to penetrate through the holes in these structures. To resolve this issue, some suggested covering the holes with vegetation or some form of solid structure, while others preferred replacing them with alternatives such as trees or additional canopies. Some students complained about the lack of autonomy when using canopies, as they were reliant on adults to open them.

> "Since the pergola has holes, it doesn't provide much shade." (student) (Fig. S1)
> "We can't open and close the canopy by ourselves. The school caretaker has to do it and sometimes he's not there." (student)

Students and teachers believed that, under normal conditions without COVID-19 restrictions, blue elements could be used for hydration and cooling on hot days. However, some students suggested that adding fountains in better locations could increase the cooling ability of the schoolyard. They agreed that water usage was limited by COVID-19 restrictions, but they also believed that water access was further limited by school policies that banned students from getting wet during school hours. Moreover, some teachers found the height of the fountains unsuitable for children, and both teachers and students expressed concerns about using water for play, which could be seen as contradicting the message of not wasting this natural resource.

"Without COVID, we think the fountain would be useful and would make us feel good on hot days." (student) (Fig. S1)
"You can waste a lot of water when playing with it." (student)

3.2.2. Play and social behavior

Students and teachers believed that there were gender differences in how children occupied the space and the type of activities they engaged in during break time prior to the transformations. Both groups agreed that, before the implementation of the intervention, the limited variety of areas available restricted students to mainly playing football or other sports on the sports court. They also highlighted that boys dominated the central areas of the space, using the sports court to play football, whereas girls mostly stayed on the sidelines.

"We say the schoolyard has been democratized because, before the intervention, there was no shade and boys played running games and football, whereas girls didn't participate in these types of games and stayed on the sidelines looking for shade." (teacher).

According to students and teachers, replacing hard materials (e.g., cement) with natural components, as well as incorporating shade and seating structures, contributed to the democratization of the schoolyard. They believed these types of changes created a greater variety of play options, which reduced the emphasis on football as the main activity and encouraged students to share and use the space more inclusively. They reported that, while playing sports decreased after the intervention, quiet activities (e.g., sitting, chatting, resting, reading, playing board games, eating a snack) and light or moderate intensity games (e.g., chasing games) increased due to the addition of shaded and seating areas. Playing in water fountains was also identified as an enjoyable activity that improved student's comfort and provided refreshment, especially on hot days. While most students preferred the transformed schoolyards, those who were more engaged in sports complained that the changes reduced their opportunities for fun because there was less space for sports and running around.

"Football tyranny is a thing of the past. We've got lots of new shaded areas to do a whole ton of activities that couldńt be done before." (teacher)
"We used to run and move more, but now with the new areas we feel more relaxed, and we talk to each other. I think people like these new spaces more than the sports court." (student)

According to students, the interventions encouraged social interaction by diversifying the play areas. They mentioned that playing different games and using the new areas enabled them to meet new people and make new friends, while enhancing interaction between girls and boys.

"Now, boys also use the areas where we chat outside the sports court, whereas before, they only played football." (student).

Some students mentioned that the perceived reduction in temperature helped them to reduce conflict behavior.

"Before, we were overexcited because of the heat, and we used to fight. Now, we can talk to each other, and we don't fight that much, because it's not so hot." (student)

On several occasions, students and teachers reiterated that COVID-19 prevention measures had significantly affected children's behavior in terms of schoolyard use and social interactions. They noted that the movement between different areas of the schoolyard and the use of balls during recess were restricted. Each class group could only use a designated area of the schoolyard, depending on the day of the week, leading to quieter dynamics. Likewise, teachers and students also reported that children were only allowed to interact with classmates, which improved social relations within groups but limited socialization with students from other classes.

"Because of COVID-19, students couldńt use the schoolyard as they normally did. They were separated into clusters of students, which couldńt interact with other clusters." (teacher)

3.2.3. Health and well-being

In general, students reported feeling calmer, less tired, and less stressed when using the transformed schoolyards, which helped them concentrate better during classes. In particular, they noted that their well-being and relaxation were enhanced by vegetation (creating natural, appealing, enjoyable, and healthier spaces), new shaded and seating areas (enhancing thermal and physical comfort), and fountains (improving thermal comfort).

"Plants make me think about health." (student)
"Seeing all the schoolyards made of cement feels different to seeing green walls now. It [the schoolyard with green walls] is more relaxing and peaceful." (teacher)
"Before the intervention, we were always tired and exhausted. Now that we have more shaded areas, we feel calmer." (student)

Moreover, some students reported feeling safer in the newly developed areas with benches and picnic tables, as they felt less at risk of being accidentally hit by a ball. Some students also commended the use of anti-slip material around some of the fountains, which further enhanced safety.

"Now, we feel more relaxed, our breakfast won't be knocked off because of a ball, we feel safer." (student)

However, some students expressed concerns about the addition of gravel to the schoolyards as part of the interventions, as it increased the risk of slips or falls. Both teachers and students also stated that fountains used for cooling and recreational purposes created puddles that could be hazardous for students playing in the area.

"After turning on the fountain, puddles formed in the area. People could slip, it's dangerous." (student)

4. Discussion

According to our quantitative findings, perceptions of the schoolyard environment changed positively after the intervention in students in the IG compared with those in the CG. In addition, fewer boys played sports in the IG compared with those in the CG. In our qualitative research, students and teachers reported improvements in perceived thermal conditions, attractiveness, and naturalization of the schoolyard. They also noted the beneficial effect of the intervention on students' well-being, play, and social inclusion. Opportunities for further improvement were identified in terms of heat reduction, safety, water waste, and students' autonomy.

4.1. Perceptions of the schoolyard environment

After the intervention, students in the IG felt greater liking for and affinity with the schoolyard (quantitative data). Our qualitative findings suggest that this may be partly due to the incorporation of natural elements. This explanation is supported by previous investigations showing children's preferences for natural schoolyards (Lucas & Dyment, 2010; Samborski, 2010) and their appreciation of school greening (van Dijk-Wesselius et al., 2018). In our study, likability and affinity decreased in the CG, probably due to movement limitations in the schoolyard as a COVID-19 preventive measure. Notably, teachers expressed regret about the lack of green maintenance during our interviews, indicating the need to consider maintenance requirements in the design and implementation of nature-based solutions.

Our qualitative results indicated that students and teachers perceived a positive impact of the interventions on the schoolyard's thermal environmental conditions, mainly attributed to the provision of shade from both natural and artificial sources. This is consistent with previous research showing greater thermal comfort in shaded areas (Lanza et al., 2021a) and students' perception of shade sails as valuable structures for providing relief from the heat. Our findings support the importance for urban planners of designing and renovating traditional urban schoolyards by incorporating both natural and artificial shade features to improve students' thermal comfort. Our qualitative data also suggested that the greenery was not sufficiently grown and consequently its impact on heat perception was lower than expected. Therefore, long-term evaluation is required to fully assess the true impact of the implemented vegetation. Our qualitative findings also pointed to the need to increase the total number of shade structures and cover the holes in pergolas to enhance their cooling ability in future replications.

Our qualitative data showed that teachers and students recognized the potential cooling effect of blue measures. This potential has also been reported in previous research conducted in a low-income community in the U.S. (Lanza et al., 2023). However, school regulations, such as fountain closures due to COVID-19 and restrictions on getting wet, may have limited the benefits of blue measures in our study. Although there is growing interest in the potential benefits of green schoolyards, the impact of water features on thermal comfort in these spaces remains understudied. Our work contributes to this field by suggesting a positive effect of such measures on students' thermal comfort. However, future studies are needed to fully evaluate these effects beyond the limitations imposed by the COVID-19 pandemic. This would provide better guidance to policymakers and urban planners regarding the design of thermally comfortable schoolyards.

Furthermore, our qualitative results also revealed a general concern about the potential water wastage resulting from the use of fountains for play and cooling purposes. The expectation of significant increases in water scarcity due to climate change (IPCC, 2023) emphasizes the importance of reaching a consensus among schools to ensure student comfort during heatwaves, while also advocating for the responsible use of water. Other negative technical issues should also be addressed, including the insufficient number and height of some fountains, which were unsuitable for children.

4.2. Play and social behavior

Previous studies (Dyment & Bell, 2008a; Mårtensson et al., 2014; Root et al., 2017; Samborski, 2010; van Dijk-Wesselius et al., 2022) have suggested that naturalized schoolyards can stimulate play diversification. Our qualitative analysis revealed that students and teachers reported that the addition of shaded and seating areas, as well as more natural surfaces, led to more varied play. These new spaces provided alternatives for children who were less interested in sports games, who tended to be girls (Dyment & Bell, 2007; Raney et al., 2023; Root et al., 2017), thereby reducing the dominance of boys playing football in schoolyards. Similarly, our quantitative data revealed that playing sports games decreased among boys in the IG compared with those in the CG. All these findings support Affordance Theory (Gibson, 1979), suggesting that naturalized schoolyards are better suited to the interests and needs of a wider range of students. The findings also highlight the importance of designing schoolyards that incorporate a greater variety of areas and elements (e.g., shade, seats, greenery) in contrast to traditional spaces (consisting mainly of a large sports field). This design approach creates more opportunities for play and fosters inclusivity (Dyment & Bell, 2008b; Harper et al., 2021; van Dijk-Wesselius et al., 2022).

Controversy surrounds the potential of naturalized schoolyards to increase PA. While some studies found no (Mårtensson et al., 2014) or negative associations (Hazlehurst et al., 2023; Poulos et al., 2022) between green areas and students' PA levels, several others showed a positive link (Bates et al., 2018; Dyment & Bell, 2007, 2008a; Lanza et al., 2022; Raney et al., 2019; Raney et al., 2023). Other studies suggested that greening stimulates PA particularly among girls (Pagels et al., 2014; van Dijk-Wesselius et al., 2018; Wood et al., 2014). In our quantitative analysis, we found no significant changes in PA levels after the intervention in any group. However, in line with a study carried out in Australia (Martin et al., 2012) and another study in the U.S. (Poulos et al., 2022), our qualitative results suggested that the new shaded and seating areas were used for quieter and less vigorous activities. As suggested by prior literature (Fjørtoft et al., 2009; Pagels et al., 2014), this is probably because the new areas are usually less suitable for running due to the incorporation of elements that make running more difficult. On the other hand, our qualitative analysis suggested that the new naturalized and shaded areas offered different PA options, mostly light or moderate-intensity non-sports active games. These results are consistent with those of Dyment & Bell (2008a), which revealed the potential of greening schoolyards to promote light and moderate-intensity PA by increasing the range of non-competitive, open-ended play. All these findings suggest that including areas with nature, shade, and sitting options might not increase vigorous-intensity activities but do offer different PA options for a broader range of students, especially those who do not usually engage in competitive sports (Root et al., 2017).

Based on our qualitative analysis, students and teachers indicated that more varied play and the addition of new areas for socialization (shade with seating) fostered positive social interaction among students and contributed to gender-inclusive play. Previous research has also demonstrated positive results in terms of social interaction and gender inclusion in schoolyards with ample play opportunities and green spaces (Bohnert et al., 2022; Dyment & Bell, 2008b; Lucas & Dyment, 2010; Raney et al., 2023; Samborski, 2010).

During the photovoice sessions, students reported a reduction in conflict behavior during recess after the intervention. This decrease could be correlated with several factors, such as the presence of more natural and comfortable environments (Bates et al., 2018; Raney et al., 2019), improved thermal comfort in the schoolyard, as extreme heat has been related to heightened aggression and irritability (Vanos, 2015), and a reduction in sports activities, as aggressive behaviors tend to occur more commonly in traditional sports, particularly football (Raney et al., 2023). Hence, our qualitative findings support the notion that shaded seating areas exemplify how landscape elements designed to create a more heat-resilient environment for students can also foster positive interactions and inclusion.

It is important to note that the co-benefits observed in terms of play and social behavior in our study may be influenced by external factors. Firstly, COVID-19 prevention measures were implemented in schools upon reopening, which coincided with the post-intervention period. As a result, each class group was assigned to a specific schoolyard area and took turns throughout the week. In view of previous research on the impact of COVID-19 restrictions on children's PA (Do et al., 2022; Lanza et al., 2021b), limitations on movement might have affected students' play choices and decreased PA levels, which could explain the reduction in non-sports games and running observed in both the IG and the CG. In

most schools, these restrictions also limited socializing between students outside of their class group peers. Secondly, the play rules of individual schools might have also influenced play behavior and socializing (Bell & Dyment, 2008).

4.3. Health and well-being

Overall, in our qualitative analysis, students reported experiencing less stress and fatigue, as well as improved concentration, after the intervention. The students mainly attributed these improvements to a more natural and pleasant environment, reduced heat stress, and the availability of areas for quiet activities. Previous studies have consistently highlighted the potential of greenery and shade measures to enhance children's physical and psychological well-being by reducing stress (Bell & Dyment, 2008; Corraliza et al., 2012; Huang et al., 2016) and improving perceived restorativeness (Akpinar, 2016; Bagot et al., 2015; van Dijk-Wesselius et al., 2018).

Our qualitative results on the perception of safety were mixed. Students (photovoice) and teachers (interviews) voiced concerns about the increased risk of injury due to puddles created by fountains, while students not engaged in sports reported feeling safer in the newly shaded areas of the schoolyard. Previous evidence supports the notion that replacing hard surfaces with softer materials can reduce injuries in the schoolyard instead of increasing them (Bates et al., 2018; Bell & Dyment, 2008). Our qualitative findings suggest the need to improve the design of water features and confirm that heat-adaptation measures can also provide safe and comfortable spaces for relaxation in the schoolyard (e.g., combining shade structures with benches), which may positively impact children's well-being.

Our quantitative data indicated that boys in the IG scored higher than those in the CG for quality of life, and physical, psychological (close to significance), and school well-being, while no differences were found among girls. In agreement with our results, Akpinar (2016) found a more restorative effect of schoolyard greenness in boys than in girls and observed a positive association between naturalness and stress levels only in boys. These findings have several possible explanations. Firstly, the quantitative health indicators included in our study are generic measures of children's well-being, which may be influenced by several individual and contextual factors. For instance, the COVID-19 pandemic greatly affected children's perceived health, especially among girls (Zhou et al., 2020; Pizarro-Ruiz and Ordóñez-Camblor, 2021). Therefore, the potential effect of the intervention on health might be obscured by the COVID-19 pandemic, especially in the female group. Another possibility is that heat reduction may be more beneficial in boys, as they tend to be more active during recess (Lemberg et al., 2023; Pagels et al., 2014), leading to more pronounced reductions in stress levels and aggression. However, these results should be interpreted with caution, as only post-assessment measures were available to compare health indicators between the groups. Future studies should explore pre-post changes in student's health outcomes before and after schoolyard heat adaptations, analyzing the impact on girls and boys separately to confirm or refute our current findings.

4.4. Limitations and strengths

The main limitation of this study is the closure of schools in response to the COVID-19 outbreak. Questionnaire data could not be collected before the intervention, as originally planned, resulting in the inclusion of retrospective questions for most pre-intervention indicators, except for general health quantitative indicators. Moreover, pre- and post-intervention questions were collected in different seasons (November and May) with potentially varying weather conditions, which may have influenced students' responses. This adapted evaluation design may have introduced recall and social desirability biases, which should be considered when interpreting the results. However, a combination of quantitative and qualitative techniques was used to analyze data consistency and a CG was included to minimize potential limitations.

The use of subjective self-reported measures for the quantitative evaluation can also lead to recall and social desirability biases. We used validated and reliable self-reported measures, piloted our questionnaire and included a CG in the study design to minimize potential biases. Given the inherent subjectivity and potential biases associated with self-reported data, future research could benefit from incorporating objective measures to complement and expand upon the current findings.

The qualitative evaluation is limited by the absence of inter-coder reliability testing. However, ongoing discussions among research team members were held to refine the coding scheme and identify any discrepancies in interpretation, thus minimizing this limitation.

Another design limitation involved the selection of schools, as intervention schools were generally more vulnerable to climate change than comparison schools. In addition, student's perceptions of the schoolyard environment were significantly worse in the IG than in the CG in pre-intervention measures. Moreover, schools differed in neighborhood SEP, and consequently models were adjusted for this variable. Further studies are needed to investigate whether the effects of interventions vary according to SEP. Regarding the qualitative data, student recruitment for photovoice sessions was based on students' motivation and included only those involved in the co-creation process; therefore, the results might not be representative of all student profiles in the schools. However, the sessions were highly participative and allowed detailed exploration of students' perceptions and experiences.

There is a major need to evaluate innovative urban interventions aiming to adapt schools to climate change. We identified the strengths and limitations of these urban planning interventions and provide suggestions to enhance their effectiveness in future implementations on a larger scale. Importantly, we included children's and teachers' voices, considering their perspectives, to develop urban policies and programs that directly affect them. A further strength of our study is the use of a mixed-methods approach with multiple methodologies (questionnaires, photovoice, interviews), the analysis of multiple outcomes, and the incorporation of a CG, which allowed us to minimize potential threats to internal validity. Furthermore, our study is the first to evaluate the impact of the combination of three types of heat-reducing measures (green, blue, and gray) for school adaptation in a Mediterranean context.

5. Conclusion

Implementing pilot projects with robust evaluations helps generate evidence on the benefits of these types of interventions and build public and political support for the wider adoption of similar projects. The present study provides valuable results for urban planners and policymakers in other cities with contexts similar to Barcelona to promote heat-resilient schoolyard design. Mixing different cooling interventions (green, blue, and gray) and naturalizing the schoolyards may improve students' perceptions of comfort, stress and safety, and enhance their concentration. In addition, climate-adaptation strategies in the schoolyard, particularly shaded and seating areas, can create alternative areas that offer varied play opportunities and places for relaxation and socialization in a more inclusive way. Users' considerations should be taken seriously to improve this intervention in future replications. Furthermore, maintenance efforts for naturalized solutions should be considered before implementation. Further research is needed to fully evaluate the potential effect of water features and the long-term impact of vegetation. Future interventions should ensure sustainable and responsible use of water. Overall, the positive outcomes in our study suggest a potential value for replication.

Ethical considerations

The study was conducted in accordance with the Good Clinical Practice Guidelines of the Declaration of Helsinki. The protocol study

was approved by the Parc de Salut Mar Clinical Research Ethics Committee (2019/8820/I). Written informed consent was obtained from students' families and teachers.

CRediT authorship contribution statement

Marta Sanz-Mas: Writing – original draft, Investigation, Formal analysis, Data curation. **Xavier Continente:** Writing – review & editing, Validation, Methodology, Investigation, Conceptualization. **Sílvia Brugueras:** Writing – review & editing, Methodology, Investigation, Conceptualization. **Marc Marí-Dell'Olmo:** Writing – review & editing, Methodology, Conceptualization. **Laura Oliveras:** Writing – review & editing, Validation, Investigation. **María José López:** Writing – review & editing, Supervision, Methodology, Conceptualization.

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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2024.105206.

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