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Physical workplaces and human well-being: A mixed-methods study to quantify the effects of materials, windows, and representation on biobehavioral outcomes

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ABSTRACT

Increasing evidence suggests the built environment can impact occupants' attitudes, behavior, and health. However, few studies have examined these links with large samples in controlled settings. To address this gap, we conducted an experiment ($N = 413$) with varied physical features (i.e., materials, windows, and artwork representing diverse identities) to test their effects on biopsychosocial indicators of well-being including belonging, stress, creativity, and pro-environmental concern, measured through physiological sensors and self-reported assessments. Consistent with our hypotheses, participants exposed to natural materials and windows during a stress-inducing task had lower negative stress impacts across various metrics. For certain subgroups, exposure to natural materials also resulted in increased divergent creativity while exposure to windows resulted in increased charitable donations. Finally, participants exposed to diverse representations reported lower stress levels. We discuss the implications of these findings, including methodological challenges surrounding the design, experimentation, and operation of human-centered built environments.

1. Introduction

In the United States and similar post-industrial countries, people now spend 87% of their time in buildings [1], making indoor built environments powerful yet underleveraged loci for promoting human well-being. In this research, we examine the effects of built features on

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information workers' individual well-being in office environments. Information and knowledge work is one of the fastest growing economic sectors in developed countries, currently comprising more than 40% of the U.S. workforce [2] and essential to competitive success of organizations internationally [3]. Beyond individual benefits, enhancing employee well-being can drive pivotal organizational outcomes including improvements to: recruitment and retention [4], product innovation [5], workforce diversity [6], employee turnover [7], market share [8], and profitability [9]. As an example, a small change in the working environment to integrate indoor access to natural elements could potentially recoup up to $23 billion in the economy, given 10% of workplace absenteeism, which costs $226 billion annually, has been attributed to architecture that inadequately connects to nature [10].

There is growing evidence of the substantial impacts indoor built features may have on office occupants [11–14]. Specifically, several case studies indicate that the physical environment positively influences employee productivity [15], social interactions [16], physical activity [17], physical health [18], and psychological wellness [19]. Much of the scientific attention has been on the impact of indoor environmental quality (IEQ) on occupant well-being [20–22] with research utilizing data from real buildings [23–26], living labs [27], and controlled experiments [28]. Overall, optimizing IEQ can have a positive impact on occupants, for example, better air quality can double workers' cognitive scores [29].

1.1. Natural materials and biophilic design

Beyond IEQ, research has examined how office layout [30,31], workspace design [32,33], and facilities satisfaction [34] impact well-being. In particular, there has been a growing interest in understanding the impact of incorporating nature and biophilic design into offices [35–38]. Studies have found that specific biophilic elements like plants and green walls can increase positive emotion while decreasing negative emotion [39], reduce state anxiety [40], improve cognitive performance [41], and enhance creativity [42]. The use of wood materials has also been found to have a positive impact on occupants' physiological response, affective state, and cognitive performance both through visual exposure in person and in virtual reality [43–45] and other senses such as touch and smell [46–48]. However, most of these studies had limitations including small sample sizes, limited participant demographics, no control conditions, limited measurements, and within-subjects study designs, which may have resulted in participants not being blind to the research hypotheses [44,46]. Most relevant to our study, participants in rooms with wood furniture had lower stress levels measured through salivary cortisol concentration than when in rooms with artificial furniture in a within-subjects study [49]. The same finding was observed with a single-blind, between-subjects study [50]. Neither study was able to observe consistent changes in stress recovery.

1.2. Windows

Windows, by providing a view to nature and access to natural light, may improve workplace well-being [51,52], and early research in hospitals has linked windows to improved patient outcomes [53,54]. Case studies around office buildings have also reported positive outcomes in terms of discomfort, stress, work ability, work satisfaction, and well-being (hedonic, eudaimonic, and negative) with windows [55–58]. Recent research has looked at how individual measures of satisfaction with space and emotional response are impacted by window size [59,60] and stress is impacted by view composition [61], though these studies were based solely on self-report. Most relevant to our research are studies that associate knowledge workers' views to nature and light with increased creativity [62], improved cognitive performance [63–65], and decreased stress [66]. However, two of these studies [64,66] had small sample sizes and participants were exposed to multiple conditions, which may have alerted them to the space manipulations. Another study [62] had a larger sample size but used a survey approach that only allowed for self-report data for both the creativity and work environment measures; furthermore, windows were combined with 11 other physical environment elements identified previously as potentially being related to creativity and thus the impact of windows could not be isolated.

1.3. Representations and iconography

Several recent studies indicate that physical cues that signal inclusivity in workplace and education environments may increase one's sense of belonging [67] and possibly reduce stress. One series of studies investigated the role of the physical environment in computer science labs [6] and virtual classrooms [68], finding that stereotypical masculine objects discouraged women's sense of ambient belonging and subsequent interest and expected success in computing, but did not have a similar effect on men. In another study [69], women who viewed a conference advertising video with unbalanced gender representation reported less desire to participate and lower sense of belonging compared to women shown a version of the video with balanced gender representation. In other research, African American professionals experienced distrust and identity threats (e.g., concern about devaluation and degree of fit) in environments with cues that promoted "colorblindness" rather than valuing diversity [70]. While such work illustrates how representations may impact attitudes, all studies except the latter most focused on undergraduate populations in academic settings, and all had sample sizes under 100. Furthermore, none of these studies looked at how representational cues interact with other physical features of a space.

1.4. Present research aims

While intuition and prior research have highlighted the important role of the physical work environment when it comes to occupant experiences, further research is needed to address the many remaining gaps (e.g., [71]). For example, much of the prior work is largely based on self-reported outcome data from a singular or pre-post surveys, and would benefit from updated examination using more multimodal and continuous measures. Specifically, experimental studies have not systematically tested how the presence of natural materials, windows, and iconographic decor in office spaces—individually and in combination—impact a battery of social, cognitive, psychological, and physiological variables.

Our research examines these outcomes, which comprise the key dimensions of well-being [72,73]. For scope and feasibility, we focus on one outcome from each well-being dimension belonging (social), creativity (cognitive), and stress (psychological and physiological), along with pro-environmental concern and behavior given the growing emphasis on conservation and sustainability in the context of building design. To further add new levels of understanding to the literature around these human–building links, we employ a mixture of measurement techniques, including passive wearable and environmental sensors, self-reported assessments, and objective tests. Various metrics for IEQ are monitored in this research (to ensure they are kept within acceptable ranges) but are not directly manipulated. Overall our research aims to quantify the impact that various components of the physical workplace can have on individual well-being, even through limited exposure.

2. Materials and methods

2.1. Overview of research design

We conducted two studies, each aiming to address inherent methodological shortcomings of the other (a consideration we reflect on in Section 4) and together paint a fuller picture of how built features impact human well-being. First, in January 2018 we conducted a pilot study that used an online survey paradigm, which enabled affordable and efficient engagement with a very large sample, to assess whether images of different work environments influence participants' self-reported belonging, self-efficacy (this was used instead of creativity and stress), and environmental concern. Next, we used an in-lab experimental paradigm, which provided a carefully controlled simulated work environment where subjects could be directly monitored and multimodal data collected, to measure participants' levels of belonging, creativity, stress, and environmental concern and behavior. In both studies, we investigate the role of 1) natural versus artificial materials (i.e., furniture and decor), 2) windows (i.e., natural light and view of nature) versus no windows, and 3) diverse versus non-diverse representations with respect to race and gender (i.e., photographic decor).

2.2. Pilot study: online survey

In the pilot study, we carried out an online experiment to examine how different work environments impact self-reported belonging, work-related self-efficacy, and pro-environmental concern.

2.2.1. Participants

Respondents were recruited using Amazon Mechanical Turk; inclusion criteria required at least a 95% task approval rate and being based in the United States. A total of 304 individuals completed the online study. Data from 32 subjects were excluded from our analyses for failed self-report data quality checks (e.g., responding "No" to the question "Did you give this survey your full attention?"). A total of 272 responses were included in the final data analyses; these participants' demographics are summarized in Table 1. Note that including all participant data ($N = 304$) does not significantly alter observed results.

2.2.2. Environmental stimuli and design

Participants were instructed to imagine they were starting a new job and were shown pictures of their new work environment (Fig. 1). Participants saw a total of six different photo collages (five images per set) with each presenting spaces based on our independent variables: natural or artificial interior materials, window or windowless space, and diverse or non-diverse iconography. Images were presented using a within-subjects design, such that all participants saw all sets of images in a random order. Diverse iconography represented racially varied people who are primarily women, and non-diverse iconography depicted only white men. Indoor spaces were chosen so that each photo set contained a meeting room, lobby or common area, hallway or corridor, and workspace or computer cluster, to reduce confounding effects associated with the type of space shown. Participants were then asked to answer a series of questions adapted from established instruments to measure: (i) sense of belonging [74], (ii) work self-efficacy [75], and (iii) environmental concern [76].

Table 1
Demographic information for online pilot study participants.

Variable	Attribute	Number	Percent
Gender	Female	141	51.8%
	Male	131	48.2%
Race	Asian, Asian American	20	7.4%
	Black, African American	19	7.0%
	Hispanic, Latina/Latino American	20	7.4%
	White, Caucasian, European American	199	73.2%
	Other	5	1.8%
	2+ Races	9	3.3%
Education	Less than a Bachelor's Degree	127	46.7%
	Bachelor's Degree or Higher	145	53.3%
Age	Mean (Std. Dev)	36.1 (10.7)	–
	Range	18–67	–
Number of Participants after Exclusions (Exclusions)		272 (32)	–

2.3. Main study: experimental lab study

The main study employed a between-subjects experimental design that exposed each participant to one of eight possible rooms that were identical in every way except for the three manipulated elements of interest: materials, windows, and representations. Specifically, these three indoor features were systematically varied to more accurately determine whether built features cause human health and well-being outcomes (belonging, stress, pro-environmental concern, and creativity). Exposure to natural versus artificial materials was implemented as a binary room condition based on the furniture and room decor being primarily composed of either stained natural wood or white plastic laminate. Exposure to natural light and a view of nature versus no natural light and no view of nature was implemented as a binary room condition based on either the presence of a window or lack of a window. We manipulated diverse versus non-diverse representations using three framed photographs containing groups of people that reflected either diverse gender and racial backgrounds or non-diverse (i.e., all white males) backgrounds. Fig. 2.b provides a graphical overview of the eight possible room configurations based on these three independent variables.

Our pre-registered hypotheses (osf.io/cwnt9) predicted that participants exposed to windows, natural materials, and diverse racial and gender representations would experience: 1) a greater sense of belonging to the university community, 2) reduced stress during a stressful activity, 3) increased creativity, and 4) greater pro-environmental concern and increased charitable behavior related to a pro-environmental cause compared to those exposed to artificial conditions and non-diverse racial and gender representations.

2.3.1. Participants

Given our research scope is information workers and work environments, we aimed to recruit a subject pool of university affiliates with some amount of professional experience, which helped minimize individual differences related to participants' employing organization and familiarity level with the area where the mock office was located. Specifically, we made the study open to staff, faculty, graduate students including co-terms (i.e., fifth year undergraduates pursuing a master's degree), post-docs, and visiting scholars. Our aim was to recruit roughly the same number of university employees and graduate students as well as representative samples based on demographic characteristics including male-female, age, and ethnicity.

Participants were recruited through physical flyers, various university affiliated email distribution lists, and a university affiliated job posting site. Interested individuals were instructed to fill out a brief online survey that collected their contact information (i.e., email address and phone number) and university affiliation, which was then used to screen for eligibility (i.e., over 18, university-affiliated, and non-undergraduate status). If eligible, respondents were sent a follow-up email with instructions and a link to schedule an in-person experimental session using the software Acuity™. Both pilot and study participants were paid a $25 Amazon gift card upon completing the experimental session.

To determine a sample size with sufficient statistical power, we referenced previous studies related to our environmental stimuli such as prior work on how diverse representations influence social and psychological outcomes and behaviors [6,69], which have observed medium effect sizes: partial eta squared = 0.15 to 0.17, $f^2 = 0.42$ to 0.45. Using a conservative estimate, we used the program G*Power [77] to identify the sample size corresponding to a 95% chance of detecting this effect (ANOVA: fixed effects, special, main effects and interactions; 2 groups; df = 1; partial eta squared = 0.15, $f^2 = 0.42$). These analyses revealed that a total sample size of 76 participants would yield sufficient power. However, it is possible that the strength of the effect may change, for instance due to social, political, or cultural shifts that have occurred since those studies were conducted or the fact that they sampled

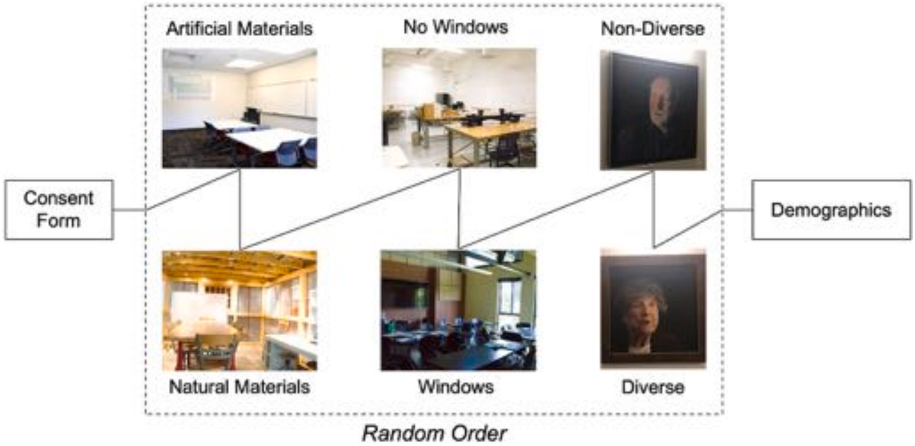

Fig. 1. Graphical overview of protocol for the pilot study with an example stimuli image for each presented theoretical work environment (natural versus artificial materials; window versus no window; diverse versus non-diverse elements).

university students whereas our study samples young, midlife, and older adults. Therefore if the effect is smaller than has been previously found (partial eta squared = 0.05, $f^2 = 0.22$), then a sample of 249 would be needed to find a small effect with 95% confidence. This same sample size would be sufficient to test interactions with participant race/ethnicity and gender.

To buffer against potential data loss due to unanticipated problems (e.g. equipment failure, participant dropout etc.), we built in an extra 20 participants per condition, bringing our minimum target N to 409. Ultimately, a total of 421 participants were recruited and completed study sessions between May 2019 and March 2020, though eight participants were excluded due to unusual circumstances around their sessions (4), RA/manager protocol error (3), and participant non-compliance with instructions (1). The demographics of the remaining sample with 413 participants are summarized in Table 2.

2.3.2. *Environmental stimuli and design*

All studies were conducted in two rooms on the third floor of a mixed-use academic building on our university's main campus. These spaces were previously used as private offices and had an approximate size of 16 feet by 10.25 feet (165 sq. feet, 15.3 sq. meters). Both rooms had white walls, a visible concrete column/beam, brown carpeting, dropped acoustic ceilings, four rectangular ceiling lights, an AC ceiling vent, a light switch, and a thermostat (one room's thermostat was digital while the other room's thermostat was manual, but both thermostats were the same size and in the same location), and floor to ceiling glass windows (with the bottom half painted with light blocking paint) on the exterior wall. Fig. 3.a shows the view out the window from the participant's seated position. As can be seen in the photograph, the view out the window was of the sky, neighboring building, and a small canopy of primarily evergreens, and did not change in a qualitatively noticeable way over the course of the year.

In creating the no window condition, we found that temporary window-covers were distracting and insufficiently blocked the natural light. We therefore covered the window in one room with drywall in order to create the appearance of an interior room with a windowless environment (Fig. 3.b). We acquired two complete sets of comparable furniture and room decor, one with natural materials and one with artificial materials. Each materials set contained: two 49″ by 29.5″ tables pushed together to create a roughly square table, six chairs, two console tables, three 16 inch by 20 inch picture frames with color photos, and a small table organizer. The aforementioned sets of three "diverse" and three "non-diverse" photographs were swapped into wall-mounted frames depending on the experimental condition. Representations were selected from the university's available media photos. Photos for the non-diverse condition showed only white men, while photos for the diverse condition showed various racial and gender groups (see Fig. 2.c). All the potential diverse and non-diverse images were coded in terms of indoor/outdoor setting, group size, visible university affiliation, age, gender, race, power dynamic, affect, and candid nature. The final diverse and non-diverse images pairs were then selected to be similar. The final images were pre-tested among a university sample based on the following adjectives on a 5-point scale (1 = Not at all, 5 = A great deal): diverse, natural, dramatic, realistic, relatable, and off-putting (results available upon request). Valence was also pre-tested using a 7-point scale (1 = Extremely negative, 7 = Extremely positive). In terms of diversity, the selected diverse images' (3.31, 3.37, and 3.83) average score was higher than the non-diverse images' (1.68, 1.75, and 2.09).

Minor cosmetic upgrades (e.g., paint touch-ups, leveling the dropped acoustic ceiling) were performed to make the rooms as similar as possible. Regardless of the experimental condition, a wall-mounted flatscreen monitor, monitor remote (in table organizer), wall-mounted whiteboard, and small combined recycling/trash bin were placed within the room; and a blue fabric waiting area chair and informational poster were placed outside the door in the hallway.

2.3.3. *Well-being measures*

As seen in Fig. 2.a, the four main study phases (which each aimed to measure our well-being outcomes of belonging, stress, environmental concern, and creativity) were counterbalanced with filler tasks and randomized across participants. For each well-being outcome except for belonging, both self-report and objective (physiological, scored, or behavioral) metrics were used. Table 3 provides an overview of these well-being metrics, with detailed descriptions of each instrument in the Online Appendix.

A Qualtrics survey was used to collect participants' self-reported, scored, and behavioral well-being measures. The survey also included an exit survey involving open-ended questions about the study (see Section 3.2.6), institutional trust [87] privacy and information sharing attitudes [88,89], and demographics. To collect physiological data, all participants wore an Empatica E4 device that measured skin conductance response (SCR).

2.3.4. *Study procedure*

The Stanford University Institutional Review Board (IRB) reviewed and approved all methods and materials related to this experimental study (Protocol #48481). Participants signed up for a study ostensibly on professional development resources. This cover story was intended to ensure participants were in a work state of mind during the study and would not focus on the experimental conditions. Each in-person, approximately 1-hr experimental session was overseen by a researcher

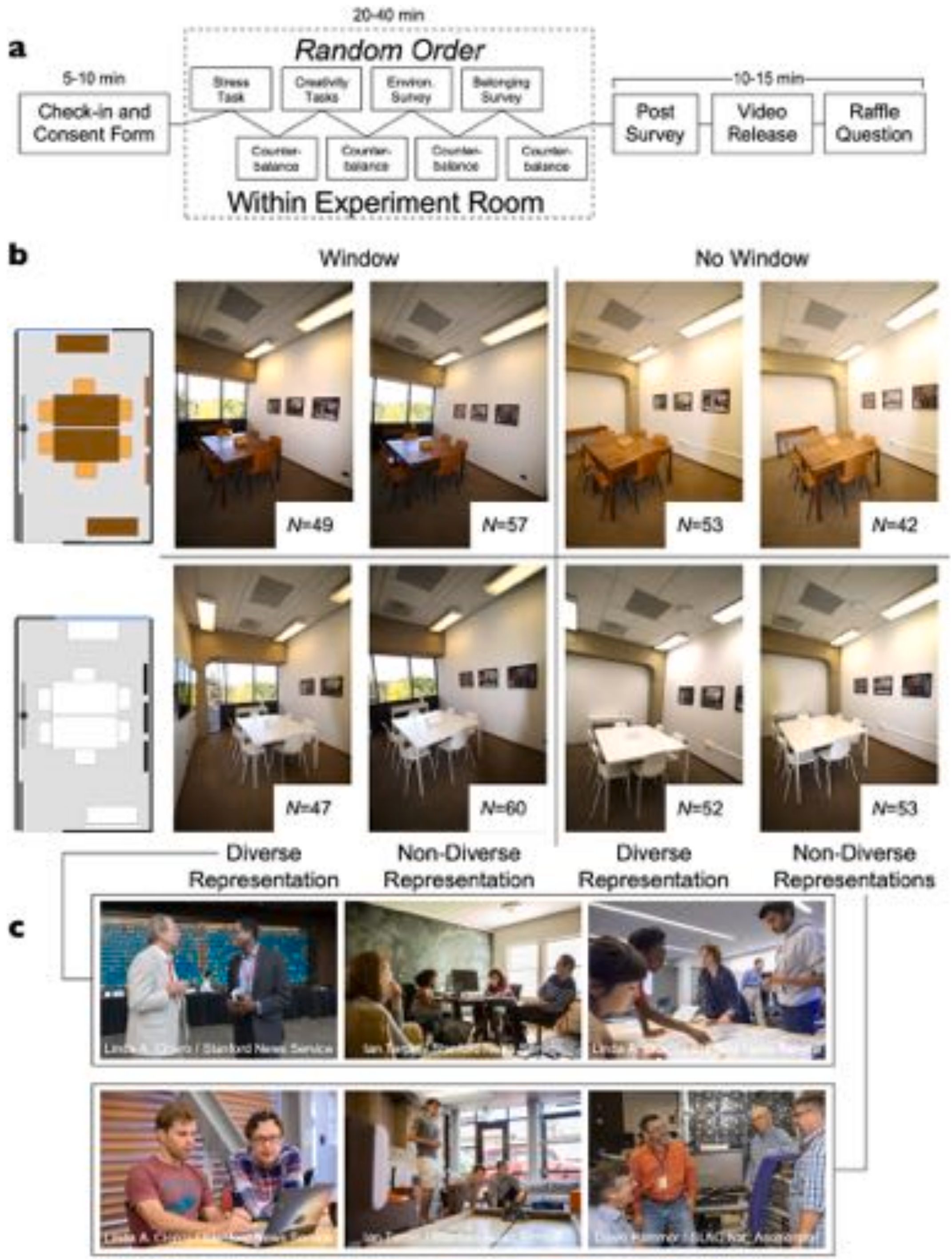

Fig. 2. Main study overview. **a**, Graphical overview of protocol. **b**, Breakdown of room conditions by independent variables. **c**, Diverse and non-diverse representations imagery.

in a supervising role and a research assistant (RA) blind to the main research questions and hypotheses. Participants were also kept blind, with all communication and instructions maintaining the cover narrative. All in-person interactions with participants were done by the blinded RA following a set script. The RA would interact with the participant upon their arrival to the designated waiting area and their exit from the study area. All other in-session instructions to the participant were delivered through the previously described Qualtrics survey that walked them through the series of study tasks and self-assessments. A supervising researcher was present at all sessions and was responsible for remotely starting and stopping data collection from the room's environment sensors as well as updating the experiment log.

The room conditions were randomly assigned each day by the supervising researcher, and the appropriate room configurations were executed by members of the research team prior to scheduled sessions. The protocol and measures were the same for every participant. Once a participant arrived in the waiting area, they were randomly assigned to one of the two rooms using a random number generator. To enhance readings of the wearable sensors, the participant was asked to wash their hands and wrists in a nearby bathroom. Before entering the study room, the participant also completed a consent form on a study laptop. This portion of the study took 5–10 min to complete.

Table 2
Demographic information for main study participants.

Variable	Attribute	Number	Percent
Gender[a]	Female	282	68.4%
	Male	126	30.6%
	Other[b]	4	1.0%
Race	East Asian, East Asian American	96	23.2%
	South Asian, South Asian American	37	9.0%
	Southeast Asian, Southeast Asian American	18	4.4%
	Black, African American	14	3.4%
	Hispanic, Latina/Latino American	16	3.9%
	Middle Eastern, Arab American	8	1.9%
	White, Caucasian, European American	172	41.6%
	Other	5	1.2%
	2+ Races	45	10.9%
	Prefer Not to Say	2	0.5%
Education	Less than a Bachelor's Degree	10	2.4%
	Bachelor's Degree or Higher	401	97.1%
	Prefer Not to Say	2	0.5%
University Affiliation	Graduate Student	208	50.4%
	Staff	182	44.1%
	Post-Doc	18	4.4%
	Visiting Scholar	5	1.2%
Age	Mean (Std. Dev)	32.5 (10.3)	–
	Range	21–68	–
Number of Participants after Exclusions (Excluded)		413 (8)	–

[a] One participant misread this question so excluded from this demographic variable.
[b] Gender Non-Conforming, Non-Binary, Queer (provided by participants).

Upon entering the room, the participant was asked to sit at a table with the study laptop placed on it in front of them. The RA also placed the Empatica E4 device on the participant's left wrist. The participant was then left alone to complete the study tasks until they were prompted by the Qualtrics survey to notify the RA, who was sitting outside the room's closed door, that they had completed these in-room activities. Before starting on any of the measures, participants were asked to take 2 min to mentally disconnect from their daily distractions and relax. This timed period was included to allow participants to observe and engage with the room without explicitly calling attention to the physical space. This portion of the study took an average of 32.5 min (M = 32.0, SD = 8.5) to complete.

After completing the in-room activities, the RA returned and took the two wrist sensors off of the participant before directing them to a chair outside the study room where they filled out the final sections of the Qualtrics survey including a video consent form and exit survey. Upon reaching the completion screen of the Qualtrics survey, the participant was thanked for their time and the study was complete. The advertised $25 Amazon gift card compensation was provided remotely to the email address provided by the participant through the scheduling software. This final portion of the study took roughly 15 min. Fig. 2.a provides a timeline summary of these study procedures.

While most of the data collection and organization was automated through an online platform controlled by the supervisor, a few pieces of data for each participant required manual uploading. Specifically, following each session, the RA checked, labeled, and uploaded a screen recording from the laptop, and the Empatica's biometric data. The stress task video and room video were also given a brief quality check while being labeled. Between each participant, the RA wiped down the work surfaces with a cleaning solution and the laptop and Empatica with isopropyl alcohol solution. An overview of the experiment sensors and data streams is provided in Fig. 4.

Prior to launching the study, 41 pilot sessions were run from March through May 2019. A verbal exit interview was conducted by a supervising researcher with each of the pilot participants. This piloting was used to debug sensors, improve the clarity of the protocol, and check for the effectiveness of the cover story. Due to the long data collection timeframe, which increased the chance of past participants disclosing study details to future participants, and the low risk to participants, the IRB approved a decision to provide no debrief after each individual session nor at the completion of data collection.

Table 3
Overview of metrics used for each well-being dimension. Further information given in Online Appendix.

Well-Being Dimension	Metric	Type	Source
Belonging	Sense of Social and Academic Fit[a] (SAF)	Self-report	Walton and Cohen [74]
Stress	Stress	Self-report	Karvounides et al. [78]
	Valence and Arousal	Self-report	Mauss and Robinson [79]
	Continuous Decomposition Analysis of Skin Conductance Responses (CDA.SCR)	Physiological	Benedek and Kaernbach [80]
Creativity	Divergent thinking brainstorming	Scored Task	Nusbaum & Silvia [81]
	Remote Associates Test (RAT)	Scored Task	Molaison [82]
	Adjective Check List (ACL) creativity scale	Self-report	Gough and Heilbrun [83] Smith and Schaefer [84]
Environmental Concern	Connectedness to Nature Scale[a] (CNS)	Self-report	Mayer et al. (Mayer et al., 2004)
	Environmental Attitudes Inventory[a] (EAI)	Self-report	Milfont and Duckitt [76]
	Environmental conservation	Behavioral	Clements et al. [85] Zaval et al. [86]

[a] Modified/Condensed.

a b

Fig. 3. Participant's view while seated during session. **a**, In the window condition, the participant could see part of a building, trees, and sky. This view did not change noticeably over the course of data collection. **b**, In the windowless condition, the participant could see a white wall with no decoration.

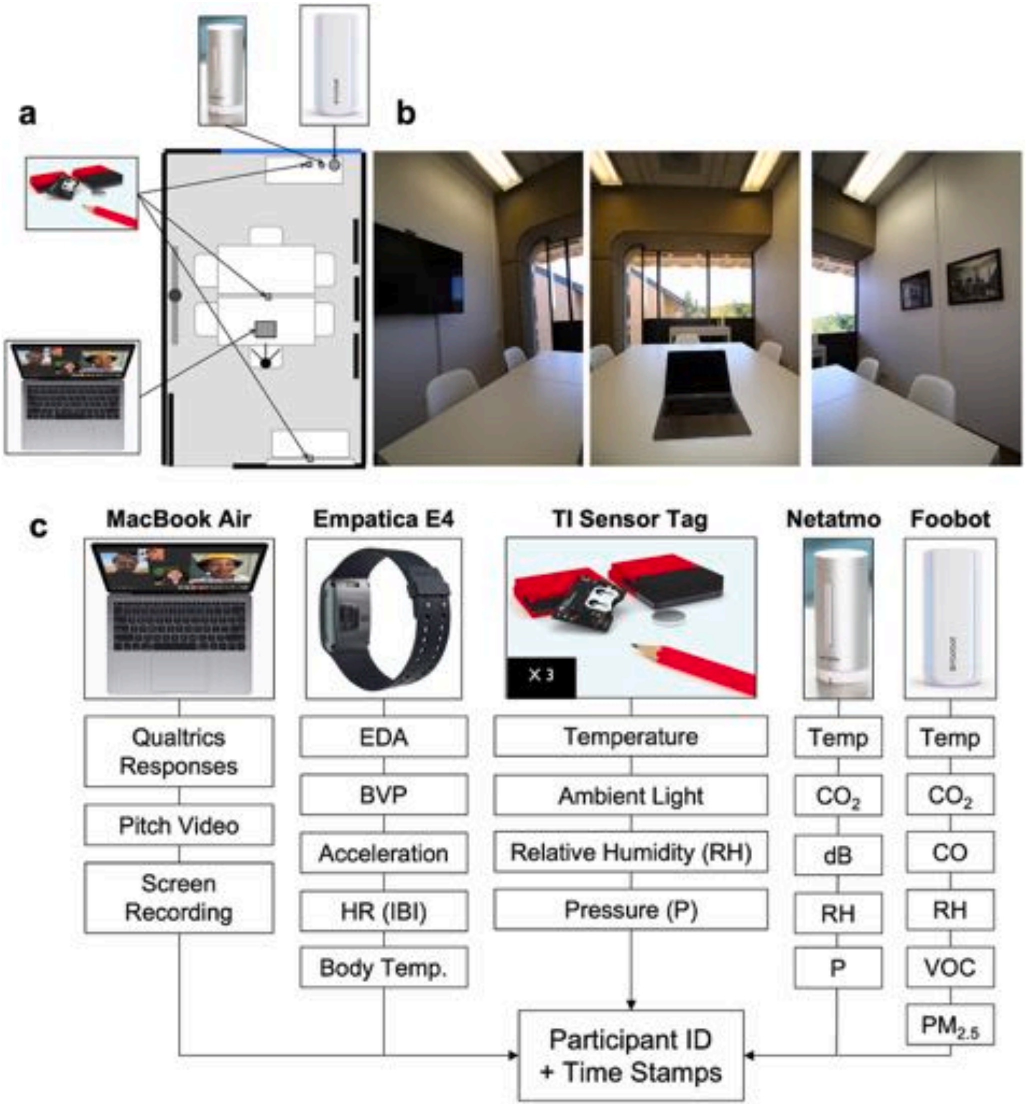

Fig. 4. Graphical overview of data collection set-up in main study experiment room. **a**, Sensor layout. **b**, Participant's view during experiment. **c**, Self-report and sensor data streams being collected per participant.

3. Results

3.1. Pilot study: online survey

Based on our within-subjects survey design, we conducted repeated measures analysis of variance (ANOVA) models. Analysis of covariance (ANCOVA) and mixed ANOVA models were also run to, respectively, control for and include interactions with the binary covariates gender (male versus female), race (white versus non-white), and education (above versus below a bachelor's degree or equivalent). The results for the main effects for the pilot study from the repeated measures ANOVA are given in Tables 4 and 5. Expanded results can be found in the Online Appendix and Altaf et al. reports further meta-analysis with four other online studies [90].

Overall, we found that the work environments that featured natural (versus artificial) materials and windows (versus no windows) were associated with higher scores across all three of the well-being outcomes we assessed (belonging, self-efficacy, and environmental concern) and had additional significant interactions with covariates (see Online Appendix). The work environments with diverse, predominantly female representations (versus non-diverse representations) were not associated with higher belonging or self-efficacy scores. However, for both

Table 4
ANOVA results for pilot study.

		Materials			Windows			Representations		
Biopsychosocial outcomes	*df*	*F*	Sign. (*p*-value)	Effect size (partial η^2)	*F*	Sign. (*p*-value)	Effect size (partial η^2)	*F*	Sign. (*p*-value)	Effect size (partial η^2)
Belonging	271	44.32	**<0.001*****	0.07	18.70	**<0.001*****	0.029	0.46	0.50	<0.001
Self-Efficacy	271	31.37	**<0.001*****	0.043	13.72	**<0.001*****	0.018	0.14	0.71	<0.001
Environmental Concern	271	39.16	**<0.001*****	0.029	23.33	**<0.001*****	0.017	7.61	**0.006****	0.005

† *p*-value ≤ 0.10; * *p*-value ≤ 0.05; ** *p*-value ≤ 0.01; *** *p*-value ≤ 0.001.

Table 5
Mean (*M*), standard deviation (*SD*), and 95% confidence interval (*CI*) for pilot study. *95% CI*'s that do not contain zero are shown in bold.

	Materials				Windows				Representations			
Biopsychosocial outcomes	Condition	*M*	*SD*	*95% CI*	Condition	*M*	*SD*	*95% CI*	Condition	*M*	*SD*	*95% CI*
Belonging	Natural	5.26	1.41	**[0.57, 1.05]**	Windows	5.04	1.45	**[0.28, 0.75]**	Diverse	3.79	1.68	[-0.16, 0.32]
	Artificial	4.45	1.57		No Windows	4.53	1.51		Non-Diverse	3.71	1.55	
Self-Efficacy	Natural	5.22	1.29	**[0.36, 0.75]**	Windows	5.08	1.25	**[0.16, 0.53]**	Diverse	4.16	1.45	[-0.23, 0.16]
	Artificial	4.67	1.33		No Windows	4.74	1.30		Non-Diverse	4.20	1.41	
Environmental Concern	Natural	5.71	1.33	**[0.32, 0.62]**	Windows	5.56	1.36	**[0.22, 0.53]**	Diverse	5.26	1.45	**[0.06, 0.35]**
	Artificial	5.24	1.42		No Windows	5.18	1.49		Non-Diverse	5.05	1.61	

belonging and self-efficacy, there was a significant gender by representation interaction resulting from opposing behaviors by gender. Specifically, participants who identified as women reported higher scores in the diverse environments and participants who identified as men reported higher scores in the non-diverse environments. The environments with diverse representations were associated with a significant increase in environmental concern, however, this effect was not significant in the ANCOVA model when controlling for the covariates. In the mixed-model ANOVA, there was a significant race by representations interaction and a significant gender by race by education by representation interaction. In both cases, certain subgroups reported significantly higher environmental concern in the workplace with diverse representations compared to the non-diverse representations (see Online Appendix).

These pilot findings supported the promising impact of workplace design decisions on well-being metrics. However, there were some limitations of this study: foremost because this study used an online paradigm, we could not test whether these effects would still be observed in actual physical workplaces and we could not control the spaces in important ways to make the conditions completely parallel. We were also unable to test our hypotheses around creativity and stress with the online paradigm used in the pilot study nor incorporate physiological measures. In addition, the lack of strong and consistent effects of representations indicated that we may have needed to refine our stimuli. To address these gaps, our main study used a large-scale controlled in-person experiment with refined physical environment manipulations to more rigorously examine the effects of these physical workplace features.

3.2. Main study: experimental lab study

Based on our 2 (Window: window versus no window) x 2 (Materials: natural versus artificial) x 2 (Representations: diverse versus non-diverse) between-subjects experimental design, we conducted three-way ANOVA models on each of the dependent variables. In addition, we added binary gender (male versus nonmale) and race (white versus non-white) variables to each of the ANOVA models to test for relevant interactions. In most cases, we report the base model statistics below for parsimony, as there were very few interactions with race and gender (except when noted). Given the homogeneity of participants' education levels (97% had a bachelor's degree or higher), education was not included as a covariate as in the pilot study. Unless otherwise specified, we removed participants whose values fell three standard deviations above and below the mean for each outcome of interest to ensure that extreme outliers are not driving any of our results.[6] Consistent with the literature on outlier exclusion [91], including these subjects yielded the same general pattern of results with very few noted exceptions. See Online Appendix for a full report of these analyses with outliers included. The results for the main effects from the interactive ANOVA (without covariates for parsimony) are given in Tables 6 and 7 and key findings are discussed further next. Specific interaction effects with gender or race are discussed when significant. The following results are organized by our biopsychosocial outcomes: belonging, stress, creativity, and pro-environmental behavior (overview of the specific measures used for each outcome are provided in Online Appendix).

3.2.1. Belonging

Based on previous research, we hypothesized that participants' self-reported feelings of belonging to the university would increase when exposed to diverse representations in the environment (see Section 1.3), and by the presence of natural materials and window, given studies that correlate exposure to nature with greater social cohesion and sense of belonging [92–94]. Our analysis did not find significant differences in the belonging scores based upon exposure to materials, a window, or representations (Tables 6 and 7). There were also no significant interaction effects between these experimental conditions or with participants' race and gender.

3.2.2. Stress

We hypothesized that participants would experience less stress when exposed to natural materials, windows, and diverse representations. We also tested whether there would be interactions with race and gender. See Tables 6 and 7 for a summary of the main effect results. An overview of the significant findings for stress is given in Fig. 5.

As seen in Table 6, from our ANOVA model for self-reported stress, we found marginal significant main effects of materials and representations. Aligned with our hypotheses, those participants exposed to natural materials reported less of a stress increase compared to those participants exposed to artificial materials. Additionally, those exposed to diverse representations reported less of a stress increase compared to those exposed to non-diverse representations. We did not find significant main effects of windows or interactions across windows, materials, and representations. There were no significant interaction effects with race and gender.

For negative arousal, our analysis revealed the predicted significant main effects of natural materials and windows but no significant main effect of representation. Specifically, natural materials were associated with significantly less negative arousal increase following a stressful task than were artificial materials. Similarly, the presence of a window was associated with significantly less negative arousal than no window. These main effects were qualified by a significant window by materials interaction, $F(1,397) = 5.45$, $p = 0.020$, partial $\eta^2 = 0.01$, such that those exposed to a window had less negative arousal ($M = 0.92$, $SD = 1.23$) than those exposed to no window ($M = 1.49$, $SD = 1.31$) when in combination with artificial materials, $t(206) = -3.23$, $p = 0.001$, *95% CI* = [−0.92, −0.22]. Similarly, those exposed to natural materials had lower negative arousal ($M = 0.94$, $SD = 1.14$) than those exposed to artificial materials ($M = 1.49$, $SD = 1.31$) in the no window condition, $t(199) = -3.15$, $p = 0.002$, *95% CI* = [−0.89, −0.21]. These results suggest that in the presence of no window (or artificial materials), having natural materials (or a window) can buffer against some of the

[6] We excluded outliers separately for each outcome because we do not believe there will be carry-over effects between the dependent variables given that participants engaged in filler tasks in between each dependent variable and completed each dependent variable in a randomly presented order. This exclusion approach allowed us to conservatively remove as few participants as possible.

Table 6
ANOVA results for the main study with outliers excluded.

		Materials			Windows			Representations		
Biopsychosocial outcomes	*df*	*F*	Sign. (*p*-value)	Effect size (partial η^2)	*F*	Sign. (*p*-value)	Effect size (partial η^2)	*F*	Sign. (*p*-value)	Effect size (partial η^2)
Self-Reported Belonging (SAF)	403	0.42	0.52	0.001	0.09	0.76	<0.001	0.44	0.51	0.001
Self-Reported Stress	396	3.54	**0.06**†	0.01	0.30	0.59	<0.001	3.46	**0.06**†	0.01
Self-Reported Negative Arousal	397	3.96	**0.05***	0.01	5.95	**0.02***	0.02	1.19	0.28	0.003
Self-Reported Positive Arousal	393	0.07	0.79	<0.001	2.78	**0.10**†	0.01	0.63	0.43	0.002
Physiological Stress (CDA.SCR)	341	4.15	**0.04***	0.01	0.27	0.61	<0.001	0.06	0.81	<0.001
Divergent Creativity	404	2.74	**0.10**†	0.01	0.64	0.43	0.002	<0.001	0.98	<0.001
Convergent Creativity (RAT)	405	0.05	0.82	<0.001	0.005	0.95	<0.001	0.60	0.44	0.001
Self-Reported Creativity (ACL)	405	0.77	0.38	0.002	0.52	0.47	0.001	0.21	0.64	<0.001
Self-Reported Pro-Env. Concern (CNS)	402	0.04	0.85	<0.001	0.27	0.60	<0.001	0.56	0.46	0.001
Self-Reported Pro-Env. Concern (EAI)	400	0.44	0.51	0.001	1.28	0.26	0.003	0.34	0.56	<0.001
Charitable Behavior	405	1.07	0.30	0.003	0.33	0.57	<0.001	0.24	0.62	<0.001

† *p*-value ≤ 0.10; * *p*-value ≤ 0.05; ** *p*-value ≤ 0.01; *** *p*-value ≤ 0.001.

Table 7
Mean (*M*), standard deviation (*SD*), and 95% confidence interval (*CI*) for the main lab study with outliers excluded. *95% CI*'s that do not contain zero are shown in bold.

	Materials				Windows				Representations			
Biopsychosocial outcomes	Condition	*M*	*SD*	*95% CI*	Condition	*M*	*SD*	*95% CI*	Condition	*M*	*SD*	*95% CI*
Self-Reported Belonging (SAF)	Natural	5.01	0.84	[-0.10, 0.21]	Window	4.99	0.82	[-0.13, 0.18]	Diverse	5.01	0.76	[-0.10, 0.21]
	Artificial	4.96	0.77		No Window	4.97	0.80		Non-Diverse	4.96	0.85	
Self-Reported Stress	Natural	1.89	2.20	[-0.83, 0.0040]	Window	2.16	2.24	[-0.29, 0.54]	Diverse	1.88	2.09	**[-0.84, -0.0047]**
	Artificial	2.30	2.07		No Window	2.04	2.04		Non-Diverse	2.31	2.18	
Self-Reported Negative Arousal	Natural	0.95	1.15	**[-0.50, -0.023]**	Window	0.93	1.20	**[-0.54, -0.056]**	Diverse	1.01	1.24	[-0.37, 0.11]
	Artificial	1.21	1.30		No Window	1.23	1.26		Non-Diverse	1.14	1.23	
Self-Reported Positive Arousal	Natural	0.30	1.31	[-0.29, 0.23]	Window	0.43	1.31	[-0.037, 0.48]	Diverse	0.25	1.27	[-0.38, 0.14]
	Artificial	0.33	1.33		No Window	0.20	1.32		Non-Diverse	0.38	1.37	
Physiological Stress (CDA.SCR)	Natural	0.017	0.023	**[-0.013, -0.00029]**	Window	0.019	0.031	[-0.0083, 0.0044]	Diverse	0.019	0.028	[-0.0074, 0.0053]
	Artificial	0.023	0.035		No Window	0.021	0.030		Non-Diverse	0.02	0.032	
Divergent Creativity	Natural	16.60	7.03	[-0.20, 2.54]	Window	16.27	7.30	[-0.80, 1.94]	Diverse	16.00	7.06	[-1.37, 1.38]
	Artificial	15.43	7.09		No Window	15.71	6.84		Non-Diverse	16.00	7.11	
Convergent Creativity (RAT)	Natural	4.43	2.49	[-0.42, 0.53]	Window	4.39	2.5	[-0.51, 0.45]	Diverse	4.50	2.50	[-0.29, 0.67]
	Artificial	4.37	2.45		No Window	4.42	2.43		Non-Diverse	4.31	2.43	
Self-Reported Creativity (ACL)	Natural	11.30	4.47	[-0.49, 1.25]	Window	10.95	4.37	[-1.18, 0.56]	Diverse	11.03	4.62	[-1.03, 0.72]
	Artificial	10.92	4.53		No Window	11.27	4.63		Non-Diverse	11.18	4.39	
Self-Reported Pro-Env. Concern (CNS)	Natural	3.56	0.52	[-0.09, 0.11]	Window	3.54	0.54	[-0.13, 0.070]	Diverse	3.57	0.52	[-0.058, 0.14]
	Artificial	3.54	0.52		No Window	3.57	0.49		Non-Diverse	3.53	0.51	
Self-Reported Pro-Env. Concern (EAI)	Natural	6.22	0.67	[-0.087, 0.17]	Window	6.16	0.69	[-0.21, 0.052]	Diverse	6.22	0.66	[-0.083, 0.18]
	Artificial	6.17	0.67		No Window	6.24	0.65		Non-Diverse	6.17	0.68	
Charitable Behavior	Natural	21.11	18.89	[-1.71, 5.56]	Window	19.60	18.74	[-4.73, 2.56]	Diverse	20.66	19.11	[-2.59, 4.70]
	Artificial	19.18	18.70		No Window	20.68	18.89		Non-Diverse	19.61	18.52	

negative impacts. There were no significant interaction effects with race and gender.

For positive arousal, we found no significant main effect of materials, windows, or representations, and no significant interactions. There was a trend for windows in the hypothesized direction with the presence of a window being associated with higher positive arousal than no window. When gender and race were added to the model, we found a significant race by materials by windows by representation interaction, $p = 0.04$, but no pattern emerged from the significant pairwise interactions.

As seen in Fig. 5, participants in the natural materials conditions had significantly lower physiological stress as captured through CDA.SCR (see Online Appendix for further explanation on CDA.SCR) during the stress task than the participants in the artificial materials conditions. While there were no significant main effects for windows or representations, there was a marginally significant windows by representations interaction, $F(1,341) = 3.61$; $p = 0.06$, $\eta^2 = 0.01$, and a significant race by windows by representation interaction, $F(1,317) = 7.03$; $p = 0.01$, $\eta^2 = 0.02$. Looking at the resulting pairwise comparisons, white-identifying participants exposed to a window had significantly lower CDA.SCR measurements ($M = 0.012$, $SD = 0.015$) than those not exposed to a

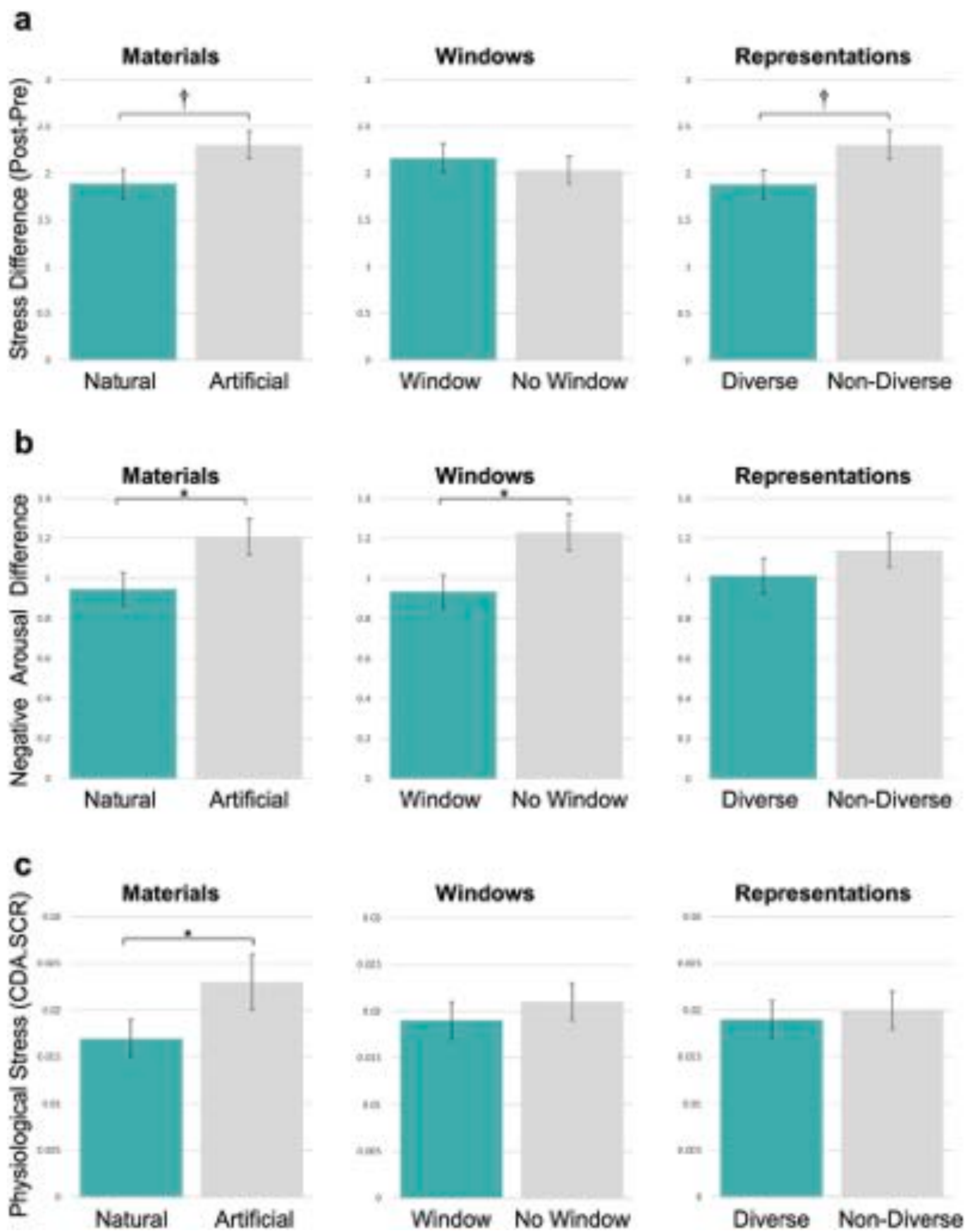

Fig. 5. Significant stress findings with standard error bars shown. **a**, Self-reported stress difference across conditions. **b**, Self-reported negative arousal difference across conditions. **c**, Physiological stress (CDA.SCR) difference across conditions. † *p*-value ≤ 0.10; * *p*-value ≤ 0.05; ** *p*-value ≤ 0.01; *** *p*-value ≤ 0.001.

window ($M = 0.031$, $SD = 0.039$) when in combination with diverse representations, $t(77) = -2.81$, $p = 0.01$, *95% CI* = [−0.032, −0.005]. Similarly, white-identifying participants exposed to diverse representations had lower CDA.SCR measurements ($M = 0.012$, $SD = 0.015$) than those exposed to non-diverse representations ($M = 0.033$, $SD = 0.047$) in the window condition, $t(75) = -2.57$, $p = 0.01$, *95% CI* = [−0.037, −0.004].

3.2.3. *Creativity*

We hypothesized that participants exposed to windows and natural materials would demonstrate higher levels of both objective divergent and convergent thinking ability as well as greater self-reported, momentary creativity (see Online Appendix for explanation of how divergent and convergent creativity tasks were scored). We additionally expected that participants exposed to diverse representations would exhibit greater creativity, considering that a person's perceptions of the work climate (e.g., supervisory encouragement, team trust and openness) can positively impact creativity [95]. We also tested whether these creativity effects interacted with race and gender. Results for the main effects are shown in Tables 6 and 7

We found no main effects of materials, windows, or representations on divergent thinking scores but the trend for natural materials was in the hypothesized direction with natural materials improving creativity. There were no significant interactions between conditions. In addition to the trending main effect of materials, there was a marginally significant gender by race by materials interaction, $F(1,380) = 3.25$, $p = 0.07$,

$\eta^2 = 0.01$. Participants who identified as male and white had significantly higher divergent creativity scores when exposed to natural materials ($M = 18.55$, $SD = 6.57$) compared to artificial materials ($M = 14.37$, $SD = 6.09$), $t(61) = 2.57$, $p = 0.01$, *95% CI* = [0.93, 7.44]. There was also a significant race by representations interaction, $F(1,380) = 4.18$, $p = 0.04$, $\eta^2 = 0.01$, however the pairwise comparisons for representations were not significant.

There were no significant main effects of materials, windows, or representation and no significant interaction effects across any of the conditions on convergent creativity. There were also no significant interactions between room condition and participants' self-reported race or gender on convergent creativity. Additionally, we found no main effects or interactions across the conditions or with race and gender on the Adjective Check List score.

3.2.4. Pro-environmental concern

We hypothesized that participants exposed to natural materials and windows would demonstrate higher levels of both pro-environmental concern and charitable behavior to an environmental cause. We were ambivalent about the impact of representation on this outcome, but tested it in the same model with windows and materials. We also tested the interactions of race and gender. The results for all the main effects on the pro-environmental measures are given in Tables 6 and 7

Our analyses of the CNS scores of participants found no significant effects of materials, windows, or representations. There were no significant interaction effects between the room conditions or with race and gender on the CNS scores either. Our analysis of the EAI scores resulted in the same non-significant findings. There were no significant interaction effects between the room conditions or with race and gender.

We did not find the hypothesized effects of material or windows on environmental charitable behavior. Additionally, there was no significant effect from representations or significant interactions between the independent variables. While there was a significant gender by windows interaction, $F(1,381) = 4.13$, $p = 0.04$, $\eta^2 = 0.01$, neither men nor women showed a significant difference in charitable donations in the window versus no window rooms upon post-hoc analysis. There was a trend, $t(126) = 1.56$, $p = 0.12$, *95% CI* = [−1.38, 11.53], for participants who identified as men to donate more when exposed to a window ($M = 20.40$, $SD = 19.61$) compared to no window ($M = 15.31$, $SD = 16.94$). There was the reverse trend, $t(287) = -1.64$, $p = 0.10$, *95% CI* = [−8.03, 0.72], for participants who did not identify as men to donate less when exposed to a window ($M = 19.22$, $SD = 18.37$) compared to no window ($M = 22.87$, $SD = 19.25$). There was an additional significant race by windows by representations interaction, $F(1,381) = 4.56$, $p = 0.03$, $\eta^2 = 0.01$. Upon examining the pairwise comparisons, there were no significant comparisons but there was a trend, $t(128) = -1.55$, $p = 0.12$, *95% CI* = [−11.09, 1.36], for participants who do not identify as white that were exposed to non-diverse representations to donate less when exposed to a window ($M = 14.66$, $SD = 17.04$) compared to no window ($M = 19.53$, $SD = 18.15$).

3.2.5. Indoor environmental quality

As part of tracking indoor environmental quality during study sessions, we focused on collecting data about indoor temperature (°C), relative humidity (%), total volatile organic compounds (tVOC), carbon dioxide (CO_2) and illuminance (Ix) levels. Sensors placed in the room logged data from 402 of 413 sessions though sessions lacked certain sensor streams; we include these partial records in our analysis.

While room-level sensors indicate that the indoor temperature was relatively steady-state throughout all study sessions (i.e., ~21 °C), our sensors indicated localized variance. As cognitive impairment may occur at temperatures greater than 30.0 °C or less than 10.0 °C, we first looked for sessions that may have been outside this range [96]. The vast majority of sessions (94.3%, 379/402) were not, though 18 sessions failed to record temperature values, and the remaining 5 sessions did not exceed 33.1 °C. The sessions that exceeded 30.0 °C all occurred in the summer, during a two day span, when the building experienced an HVAC shutdown. More than half of sessions (52.9%, 213/402) stayed within thermal comfort thresholds (as specified by OSHA [97]) of 20.0 °C and 25.5 °C while the remaining were higher but not above where cognitive impairment would be a concern.

Looking at the other sensor data, we similarly did not find any issues where cognitive impairment might be a concern. With respect to other variables closely related to thermal comfort, relative humidity between 20.0% and 60.0% is deemed acceptable (i.e., lower humidity levels might result in skin or eye irritation while higher humidity levels may result in mold growth) [97]. The overwhelming majority (93.0%, 374/402) of sessions were conducted within normal humidity ranges with 23 sessions failing to record humidity data and only a few sessions (1.2%, 5/402) exceeding the 60.0% threshold briefly. We also observed some seasonal and daily fluctuation in illuminance levels in the room with a window, the average illuminance of both rooms was generally greater than 250 Ix and less than 500 Ix which is considered appropriate for office work [98].

Average carbon dioxide levels for most sessions (64.4%, 259/402) were below 600 ppm throughout which is well within safety thresholds [99]. A small subset of sessions saw spikes in CO_2 levels resulting in averages between 600 and 1000 ppm (19.1%, 77/402) though these sessions tended to start and finish below 600 ppm. Another small set of sessions (9.7%, 39/402) saw averages above 1000 ppm. Another (6.7%, 27/402) had no CO_2 sensor readings. Though there was some concern that these CO_2 levels may have impacted our cognitive task results [100] such as the creativity tests, further analysis was unable to detect any trends in the data that would suggest this was the case. Finally, tVOC levels rarely exceeded 750 ppb (1.2%, 5/402) [101] though 42 sessions did not record data. Given participants were exposed to these conditions for an average of 32.5 min ($M = 32.0$, $SD = 8.5$), we believe these factors are unlikely to have influenced the results of our study.

3.2.6. Exit questions

To verify the effectiveness of the cover story and room manipulations, two open-ended questions were included in the exit section of the main study. The first question focused on the participants' impression of the study (i.e., "Based on your experiences during this study, what do you think this study was about?") and the second question focused on the participants' impression of the physical room (i.e., "What elements of today's experiment room stood out to you?"). Three members of the research team thematically analyzed responses to these questions using codebooks composed of inductive and deductive codes [102]. For both questions, a response was labeled with however many codes were applicable.

While a quarter (24.9%, 103/413) of participants mentioned some aspect of professional development when asked about the purpose of the study, the majority did not think the study was solely about the development of specific training exercises, which was the presented cover story. The most common response (35.6%, 147/413) was that the study was a stress experiment. While 15.7% (65/413) of responses referenced hidden variables and 19.6% (81/413) referenced the university or generic workplace environment, only 15 participants (3.6%) were able to surmise that the study was about stimuli and reactions within a workplace. One participant posited that "*This study may be related to how people's feeling of themselves can be influenced by their working environments,*" but no one specifically mentioned manipulating features of the physical or built workplace.

While the second question was intended to prompt participants to comment on elements of the physical room, only about two-thirds (62.2%, 257/413) of participants' responses included a comment about the room itself. Participants who didn't comment on the room may have overlooked that word "room" in the question or were more focused on the experiment protocol. When summarizing the coding findings from this question only the participants who mentioned the physical room will be considered.

One-third (33.1%, 85/257) of participants commented on the view or window and, given that about half of the participants were assigned to the room with no window, the percentage of participants commenting on the view or window who actually had one was closer to two-thirds (63.0%, 85/135). Two participants who commented on the windows in the study room noted the lack of a window within their normal work environment. Eight of the 122 participants (6.6%) who were in the windowless room commented on the lack of a window in the room.

The most noticed item within the rooms were the three framed photographs on the wall with more than one-third (36.6%, 94/257) of all participants mentioning them. Some participants included specific observations on the subjects within the photos such as *"the 3 pictures on the wall (and the diverse people within those pictures),"* "*the bad 'diverse' stock photos on the wall,*" and "*… the fact that all the people in the photos are WHITE MEN. Y'ALL.*" The two next most mentioned items in the room were the furnishings (35.0%, 90/257) and the environmental sensors or camera (28.4%, 73/257). Beyond the physical elements of the room, participants also commented on the lighting (10.5%, 27/257), noise (9.7%, 25/257), and temperature (2.7%, 7/257). A little under one-third (30.0%, 77/257) of participants used some combination of words like white, sterile, or stark to describe the room and 90% (89.6%, 69/77) of these participants were exposed to the room with artificial materials.

Overall, participants noticed all of the independent variable manipulations and many had an emotional reaction to the space. Generally, participants had more positive reactions to the window condition (and accompanying view) and more negative reactions to the no window condition (and bare wall). Participants had mostly neutral to positive reactions to the natural materials such as: *"minimal furniture, blank walls"* and *"It was very refreshing to be in a room with a nice view. The room was also clean and not cluttered. I really liked the wooden desk as opposed to plastic. It gave a very calm and natural feel to the entire experiment."* Participants had both negative and positive reactions to the artificial materials such as: "*Very white and sparse, looked either like a prison or a modernist apartment*" and *"The white, elegant furniture… the bright and beautiful view outside the window, photo frames on the wall and the big screen with the ability to remotely connect to meetings."* As a result, we conclude that participants were aware of the physical and digital environment around them and formed an opinion on it (when prompted) with limited exposure.

4. Discussion

4.1. Trade-offs between online and lab studies

Overall, the online survey approach, which presented participants with multiple hypothetical work environments, saw stronger effects on more well-being metrics compared to the lab study. Participants in the survey study were explicitly encouraged to notice and consciously absorb the experience of being in a given space, which may have caused a stronger response to the physical features of each room than participants in the lab experiment. In contrast, lab participants were not explicitly told to pay attention to the room features and, in fact, their participation was framed as a "professional development" study so that they would not overly fixate on the experimental manipulations, thereby unintentionally reducing the salience of the room's features.

The within-subjects design of the online study may have also accentuated space perceptions, as participants could hone in on indoor preferences after being exposed to multiple alternatives. Such findings indicate the importance of an occupant's psychological connection with a space, which may in some circumstances even outweigh the effect of bodily presence, as suggested by the outcomes of our in-person experiment. Along similar lines, the scenario presented to survey participants primed them to envision the environment as their own place of work, whereas lab participants likely associated a more transient mentality with the space they experienced, knowing their visit to the room was only temporary. Our lab study cover story may have again contributed to this psychological distance between participant and environment.

While our online survey presented respondents with close-up photos of "can't miss it" style representations (diverse/non-diverse) in posters or art installations, we used 16 inch × 20 inch picture frames in our lab study rooms to create an aesthetic, realistic feel for a workspace. Our qualitative findings from the exit questions indicate that a third of participants noticed these photos. While they were the most noticed item within the rooms, some participants may have overlooked the representations; and in conditions with the window, sunlight may have caused a glare on the frame glass that obstructed participants' views of the imagery. Unlike previous literature–including our pilot online study–which asked participants to examine and respond to clear images with various types of representations, our lab study's presentation of these images as part of the ambient environment may have reduced this variable's impact on participants' biopsychosocial outcomes. Future studies should investigate parameters such as the visibility, placement, and size of iconic artifacts, to understand how their display can be pronounced to maximize their impact on people's sense of belonging in a space.

4.2. Potential of physical workplace to improve stress recovery

In the main study, participants exposed to rooms with natural materials (versus artificial) had significantly lower increases in physiological stress and negative arousal as well as marginally significantly lower increases in self-reported stress following a stress inducing task. While past studies [49,50] reported lower overall stress from exposure to wood furniture, they did not find a significant impact on stress recovery as our results show. Our results contribute to the extant literature on the built environment by demonstrating the potential for haptic and visual exposure to natural materials, in this case wood, to significantly improve stress recovery, both psychologically and physically, after a relatively short period of exposure (less than 1 h). Incorporation of elements similar to those used in our study (e.g., wood tables and chairs, organic fabrics, stone, and wood picture frames or other decor) may therefore be straightforward interventions for interior designers and architects to implement, especially in environments where managing stress response is of particular concern and even if occupants will only be in the space briefly (e.g., clinical waiting or examination rooms, educational testing spaces, and flex work spaces). Furthermore, while many studies have focused on indoor nature such as plants and green walls [39,41,42,103], for many spaces, natural material finishes might provide a more economical and/or easily-maintainable biophilic intervention. Future work should also examine combinations of biophilic approaches.

Additionally, participants exposed to a window had significantly lower negative arousal scores and trending higher positive arousal scores. We did not observe significant differences on other stress outcomes from the presence of a window. One possibility for this null result is that exposure to artificial lighting may have an alerting effect on participants that boosted their performance in the stressor task, thereby helping to actually reduce task anxiety [104]. Another possibility is that the presence of a window may take longer to reduce stress than our study duration (less than 1 h). The potential impacts of even short exposure to windows (both physical and digital) merits further research, as another recent study found well-being improvements (including lower tension, anxiety, and claustrophobic symptoms) from being in a windowless room with an artificial skylight compared to traditional artificial lighting for 1 h [105]. Our study utilized two extreme conditions of no window or window, but there is also a need to explore windows with various blind or shading systems, particularly considering promising findings from a recent study that reported improvements in cognitive function and eyestrain for two shading systems compared to blackout blinds (mimicking no windows) but no significant differences between the two shading systems [106].

4.3. Privacy implications

Researchers interested in the human-centered design of tomorrow's built environments can leverage our work by pursuing numerous promising directions, as described above. Another area of prime importance involves better understanding and designing to satisfy occupants' acceptance and privacy concerns related to potential monitoring that might take place within intelligent spaces. In our study, we asked our participants a series of post-hoc questions regarding their general privacy attitudes and concerns, as well as several questions regarding their privacy expectations at their actual workplace (we recruited participants who were all university affiliates so that we could compare their responses in terms of the same employer and organizational context). We also asked questions involving specific scenarios of surveillance or sensing in that workplace. Several of our general questions were replicated from nationally validated Pew Research Center Internet & Society polls, and comparatively our respondents' privacy protective attitudes (e.g., over 86% of respondents agreed that "privacy is important") tracked with these past national surveys [108,109].

Overall, we found that respondents expressed a high degree in trust towards the university as an employer. When comparing responses by job category (students versus staff), we found notable differences between the groups with respect to some of these questions, indicating that one's role in the workplace may influence an individual's sense of institutional trust.[7] With significant majorities of respondents expressing high degrees of trust with how the university treats their personal information, the devices issued to them at work, their overall best interests, and an overall belief that their workplace affairs were not closely monitored, we found that even with a highly trusted employer there were limits. In posing a scenario where a workplace computer might sense one's emotional state, the majority of respondents were concerned about this scenario, specifically who could access this information (with staff reporting significantly more concern than students), and how it might be secured. Eighty-eight percent of respondents also expressed a desire not to be monitored at work. In sum, even with an employer that enjoys high institutional trust from its employees, the deployment of sensor technology and issues of invasiveness must be carefully considered. Our future research will further probe these issues, and we encourage others to do the same, as well as consider the impact of the type of information sensed, by whom it can be accessed, and for what purpose — all factors that impact individuals' acceptance of data-enabled built environments.

4.4. Limitations and recommendations

The main limitations of this work include: (i) participants' limited exposure to the study room and conditions may be responsible for some of our null results that contrast the existing literature and (ii) in an effort to avoid calling too much attention to the room, the workplace-related questions in the experimental study likely led some participants to answer with respect to their real-life working environment, rather than the study room itself. With a longer treatment time, such results may bear out as expected. In general, methodological trade-offs are important to consider as part of making such experimental design decisions. Our survey-based study was broadly scalable, relatively inexpensive, and quick to administer; however, participants could not physically experience the depicted environments, and conditions could not be tightly controlled. Our lab-based research enabled this rigorous control over study procedures and conditions; however, the overhead to prepare the lab space and conduct the study was substantial in terms of both monetary costs and researcher time, plus we faced difficulties in achieving a setup that could authentically mimic a person's everyday work environment, especially from a psychological perspective. A longitudinal field study at a real work site with real employees would enable more longitudinal, ecologically valid research; although less control would be possible, collected data would have less temporal and spatial granularity, costs would again be substantial, a partnership with an employer would need to be established and cultivated, and recruitment and adherence would be greater concerns to manage.

Recognizing this lack of a universally-optimal experimental paradigm helps to put our research's contributions and limitations into better context. For example, while most studies in the literature recruit relatively small samples or rely heavily on subjective measures [107], we have reported insights from a large scale study that incorporated physiological measurements in addition to self-report and objective assessments. Further, by publishing our null results, other researchers can avoid expending time and funding pursuing study designs that will be vulnerable to the same shortcomings that we have pointed out. These trade-offs also motivate continued research that utilizes a mix of methodologies to triangulate in on a better fundamental understanding of how the everyday work environment impacts worker well-being, in terms of multifaceted cognitive, psychological, physiological, and social dimensions using not only self-report measures but physiological and building sensor data as well.

5. Conclusion

Understanding the impact of built workplaces on individual well-being outcomes is an emerging area in need of attention. In our online pilot study (N = 272), we found that workspaces with natural materials and windows (with natural light and views of nature) elicited statistically significantly higher levels of belonging, self-efficacy, and environmental concern. These effects were especially pronounced for women who also reported a greater sense of belonging, self-efficacy, and environmental concern in spaces with representations mostly depicting racially-diverse women. Based on these findings, we then conducted a large-scale laboratory experiment (N = 413) to replicate these effects in a simulated workplace environment and to extend these findings to test the effects of our independent variables on additional outcomes of creativity and stress. The major contributions from this lab study are:

1. Natural materials significantly decreased participants' immediate stress response in both self-report of negative arousal and physiological (CDA.SCR) measures. Windows also significantly lowered self-reported negative arousal. Strong trends for natural materials and diverse representations lowering self-reported stress were observed as well.
2. Natural materials exhibited a trend for increasing divergent creativity. Specifically, participants who identified as male and white had significantly higher divergent creativity scores when exposed to natural materials compared to artificial materials.
3. There was a significant interaction between windows and gender for pro-environmental charitable behavior. The resulting pairwise trend was that participants who identified as male donated more when exposed to a window while participants who did not identify as male donated more when exposed to no window.
4. The IEQ conditions were typically kept below ranges where cognitive function would be impacted, and therefore, as expected, no trends in our outcome well-being variables were observed.

The design interventions in our studies are straightforward and can be incorporated into a wide range of work environments and office types. These and other subtle design shifts are important for continued investigation because they are economical and scalable for both new construction and remodels of existing work environments, and they have the potential to significantly improve human well-being.

[7] Students' agreement with the statement "I have nothing to hide from my university" was significantly lower than staff; when asked whether they trusted their university issued devices with their personal information, staff agreed with this statement significantly less than students.

There may be additional effects that our methodology was unable to capture, due to limited exposure to experimental stimuli. That is, participants may not have spent enough time in the space and different amounts of the independent variables may have a different impact. Future studies involving longitudinal, living lab or naturalistic field studies are needed to understand the impact of such design shifts on both acute and chronic stress, creativity, social belonging and interaction, and environmental concern. In addition, the influence of systematically manipulated IEQ on less-studied psychological factors like belonging would be of interest to explore in future experiments. By combining results from a variety of methodologies, a more complete understanding of the impact of the physical workplace on both short- and long-term well-being can be reached.

Availability of data and code

The corresponding author can provide the data and supporting materials from both the online and main studies upon reasonable request. The provided files will be anonymized to protect participants. Unless otherwise noted, all reported analysis was conducted using the statistical software R. The corresponding author can provide the analysis files supporting the findings of this paper upon responsible request.

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CRediT authorship contribution statement

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Sarah Billington reports equipment, drugs, or supplies was provided by View, Inc.

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Appendix A. Supplementary data

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