Light Everywhere: Three Studies Investigating a Wall-and-Ceiling Climbing Robot Shedding Light on the Flexible Home

Hsin-Ming Chao[1], Shivani Shrotri[2], Eleanor White[3], Bruno Tassari[4], Cheng Zhang[3] and Keith Evan Green[1,4]

***Abstract*— This paper presents *Light Everywhere*, a robotic lighting system that enhances flexibility in domestic spaces by traversing walls and ceilings to provide real-time, task-based illumination. We report a field investigation, an online study, and a between-subjects experiment (N=26) using the WoZ approach comparing *Light Everywhere* with a conventional desk lamp, evaluating perceived comfort, control, and spatial utilization. Results show the robot supports adaptive behaviors and dynamic space usage. Findings highlight the potential of robotic lighting to redefine housing flexibility and user-driven environmental control, "shedding light" on a novel HRI and smart home design.**

I. Introduction

A. Background

In residential design, flexibility has long been achieved through portable furniture and movable partitions that allow residents to reconfigure spaces for changing needs [1], [2]. As HRI advances, embedded robotic systems offer new possibilities for real-time, low-effort spatial reconfigurability.

Among spatial elements, lighting plays a key role in visual comfort, productivity [3], and relaxation [4], yet remains underutilized in flexible environments. Unlike walls or furniture, lighting transforms space through brightness, color, and position—making it inherently adaptable [4]. Robotic lighting, in particular, supports task-based illumination that responds dynamically to human needs.

Current robotic lighting systems, such as 3-DOF lamps [5] and object-tracking systems [6] automate illumination but reduce user agency. Similarly, wall- and ceiling climbing robots like *SORT* [7] and *Climbot* [8], and ceiling-based robotic systems like *AeroRigUI* [9] and *ThrowIO* [10] demonstrate mobility but offer little direct control over lighting. These limitations underscore the need for human-centered, user-controlled robotic lighting in domestic settings.

We introduce *Light Everywhere* (Fig. 1), a wall-and-ceiling robotic fixture that enhances home flexibility by allowing users to reposition it, switch modes, and create adaptive lighting zones. This system transforms lighting from a fixed utility into an interactive, spatially flexible tool

[1]Department of Human Centered Design, Cornell University, Ithaca, NY 14853, USA. hc766@cornell.edu, keg95@cornell.edu
[2]Department of Psychology, Cornell University, Ithaca, NY 14853, USA. ss3872@cornell.edu
[3]Department of Information Science, Cornell University, Ithaca, NY 14853, USA. erw79@cornell.edu, cz448@cornell.edu
[4]Sibley School of Mechanical and Aerospace Engineering, Cornell University, Ithaca, NY 14853, USA. bdt35@cornell.edu

Fig. 1. *Light Everywhere*, a robotic lighting fixture that traverses walls and ceilings, user controlled for position, lighting mode, and lighting coverage.

B. The Need for User Studies in This Research Space

Despite advances in robotic lighting, research on user experience remains limited. *Climbot* [8] and *AeroRigUI* [9] lack reported user evaluations, while studies of 3-DOF robotic lamps [5] and object-tracking lighting [6] focus on technical feasibility. User studies are essential for assessing usability and effectiveness; without them, key questions about adoption and interaction preferences remain unanswered.

II. Light Everywhere

To investigate robotic lighting for HRI and spatial adaptability, we conducted three human-centered design investigations: (1) a field study (N=15) on conventional lighting, (2) an online evaluation (N=80) of five early design concepts, and (3) an in-person experiment (N=26) with the *Light Everywhere* prototype. The in-person experiment was a between-subjects experiment in a controlled home-like setting, comparing *Light Everywhere* with a traditional desk lamp.

Our research questions are: *How does Light Everywhere support users in performing diverse tasks within a residential environment?* (*Does Light Everywhere increase users' perceived comfort in performing tasks? Does Light Everywhere increase users' perceived control in performing tasks?*) And, *How does Light Everywhere affect spatial utilization and user behavior?* By reframing lighting as an interactive robotic system, this research contributes to human-centered robotics, demonstrating how intelligent lighting can function as a flexible element in everyday living spaces.

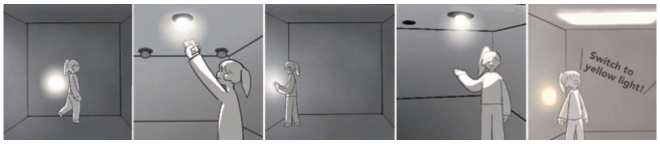

Fig. 2. Five robotic light design concepts, each represented by one frame captured from our animated GIF that was used for our online user study.

A. Field Study for Design Ideation

To understand home lighting challenges, we conducted semi-structured contextual inquiries with 15 participants (10 female, 5 male; aged 24–33, M=27.73, SD=3.06) across 13 homes. Participants walked us through daily lighting routines, demonstrating device use in context. Sessions were audio-recorded with field notes. Thematic analysis revealed issues such as limited lighting mobility, inaccessible ceiling lights, and inefficient spatial use. To address thse issues, we performed affinity diagramming and collaborative mapping towards developing five robotic lighting concepts (Fig. 2):

1) *Smart Light*: Follows users and adapts modes, easing transitions between rooms.
2) *Remote-Control Light*: Ceiling-mounted and repositionable, improving access to the "unreachable" ceiling light.
3) *Move-Your-Light*: Touch-adjustable and wall-mounted, reducing floor lamp clutter.
4) *Throw-a-Light*: Tossable ceiling light for efficient placement.
5) *Wall-Light*: Interactive walls for hand-drawing light zones and voice-controlled ceiling lighting, addressing wiring concerns.

B. Online Study for Design Evaluation

To advance our design process, we conducted an online survey with 79 participants (39 female, 37 male, 3 non-binary) recruited via the *Prolific* platform. Participants envisioned home tasks while evaluating the five design concepts introduced above, each presented with a text description, an animated GIF (Fig. 2), and a low-fidelity prototype demo video focusing on device movement and lighting adjustments. Participants assessed each concept using eight statements (Fig. 3) drawn from [11], and ranked interaction preferences for movement and lighting control.

Remote-Control Light was the most preferred concept, with the description on the survey as follows: *"Remote-Control Light" is a moving light fixture connected to the ceiling. When light is needed, you use a remote to point at a light module and "drag" it to a desired position. You can change the color and brightness of the light with the remote.* However, ranking results favored manual repositioning (Fig. 4) and voice control (Fig. 5) over remote control interaction. The next iteration integrated user-preferred features and refined interaction methods for the remote-controlled light.

C. Prototype Development

Our subsequent prototype featured: (1) wall and ceiling mobility, (2) remote control and manual repositioning, and (3) lighting mode adjustment via voice commands. Given our research interest in evaluating the early concept of robotic lighting rather than its premature technical resolution, we conducted a Wizard of Oz (WoZ) study. The experimental prototype is based on our previous work, *SORT* [7], a wall-climbing robot that moves on magnetic surfaces using two servo-driven magnet-embedded wheels remotely controlled via a mobile app developed on *MIT App Inventor* and connected to its Bluetooth module [7]. Adapting this design, we developed *Light Everywhere* with four magnet-embedded wheels, four continuous servo motors, an Arduino Nano board, an HC-05 Bluetooth module, a 9V battery, a Grove RGB LED ring with 42 programmable mini LEDs, a 5V battery to power the LED ring, and a corrugated plastic light diffuser to soften illumination. The additional two wheels and servo motors enabled ceiling movement. The mobile app was also reprogrammed to support three lighting modes with the respective RGB codes: white (255, 255, 255), bright yellow (255, 100, 0), and warm yellow (100, 40, 0). These modes reflected field study insights that users typically rely

Evaluation Statements for Each Design	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
I understand how it works on a basic level.	4.14	4.41	4.30	4.38	3.99
It will help make routine tasks easier to perform.	3.05	3.27	3.15	2.68	3.32
I could envision it in my living space.	2.59	3.25	3.25	2.72	3.09
It will make daily chores fun.	2.73	3.05	2.84	3.05	3.30
It will be easy to have it move to where I want.	3.39	3.62	3.76	3.57	3.52
It will be easy to adjust its color and brightness.	3.20	4.06	3.99	3.84	3.90
I believe it will be more helpful than my living space's current lighting system.	2.46	2.89	2.59	2.43	2.87
I'll be worried about its safety issues if it is in my living space. (*reverse-coded)	3.28	3.25	3.67	2.80	3.51
Mean Score	3.04	3.49	3.28	3.18	3.31

Fig. 3. Evaluation of 5 design concepts (1=Strongly disagree, 5=Strongly agree; Orange means scored the highest among 5 designs) drawn from [11].

	Method for Moving a Light Module	**Ranking Mean**
1	Physically move the module myself.	2.58
2	Remote control the module to move.	3.25
3	Gesture to create a light where I want it.	3.75
4	Voice-command the module to move.	3.95
5	Move the module by using an iPad app.	4.43
6	Remove the module and throw it where I want it positioned.	4.61
7	Let the module move itself where it decides I want it.	5.43

Fig. 4. Method for moving a light module: rankings of seven options.

	Method for Changing Lighting Modes	**Ranking Mean**
1	Voice-command the module to change its mood.	2.62
2	Remote control the module to change its mood.	2.86
3	Swipe on the module to change its mood.	3.11
4	Gesture the module to change its mood.	3.41
5	Change the module's mood by using an iPad app.	3.43
6	Let the module change its mood when it decides I want it.	5.57

Fig. 5. Method for changing lighting modes: rankings of six options.

Fig. 6. The prototype functions: (a) being manually moved across surfaces; (b) climbing wall and ceiling surfaces, controlled via a remote; and (c) changing lighting modes between "*white*," "*yellow*," and "*dim*."

Fig. 7. The furnished "living room" constructed in our lab, with white areas being the embedded magnetic sheets.

on no more than three primary lighting settings for domestic tasks. The modified prototype was lab-tested for lighting performance and mobility, ensuring smooth operation across magnetic walls, ceilings, and right-angle transitions.

D. Prototype Functionality

For the in-person study, a researcher covertly controlled the *Light Everywhere* prototype via the mobile app using the WoZ method, simulating two key functions.

1) Robot Movement with Remote & Manual Control: Users pointed a remote control, represented by a laser pointer, at a desired wall or ceiling location, and the prototype moved to that spot. Observing the laser point on surfaces, researchers moved the prototype accordingly. Users could also manually reposition it by detaching and reattaching it to magnetic surface areas.

2) Lighting Adjustment with Voice Control: Users changed lighting modes by saying "*white*," "*yellow*," "*dim*," or "*off*" for white, bright yellow, warm yellow, or off, respectively (Fig. 6). The default mode was white, activated by saying "*on*." Other commands were not recognized.

III. Study

We conducted a between-subjects experiment to evaluate how the robotic light both supported and impacted users performing diverse tasks within a residential environment. Participants (N=26; 16 female, 10 male; aged 22-34, M=27.19, SD=3.32), recruited from our institution's student population, were randomly assigned to the intervention group using *Light Everywhere* or the control group using an Arduino-programmed desk lamp. Each participant completed the six everyday tasks identified in Fig. 8, as will be elaborated.

A. Setup

The experiment was conducted in an 8 × 10 × 8 ft. "living room" within our lab, partly lined with thin steel sheets measuring 4 × 9 ft. on the ceiling, 4 × 3 ft. on one wall, and 4 × 6 ft. on another wall, that provided the necessary magnetic support on essential areas of the room that ensure flexibility, as informed by our field study. The space included a dining table, a coffee table, a writing desk, two rolling chairs, a sofa chair, and a ladder for manually repositioning the prototype (Fig. 7). A floor lamp near the dining table provided fixed ambient lighting commonly seen in a home setting.

For task lighting, the intervention group used *Light Everywhere*, while the control group used an Arduino-modified commercial gooseneck desk lamp, plugged into a wall outlet via a power cord and operated by a button on its base. We retained the lamp's physical appearance, gooseneck design, and button-based controls to simulate commercially available products while replacing its light bulb with the identical RGB LED ring and light diffuser as *Light Everywhere* to ensure consistent light quality.

At the start of each session, the lamp was placed on the writing desk, and *Light Everywhere* was wall-mounted near the same place. Both emitted a default white light, adjustable to bright and warm yellow using identical Arduino settings. All other environmental conditions, equipment, and materials remained constant across groups.

B. Procedure

To study flexibility in the home environment, we designed our study based on common home activities, drawing from the framework of Activities of Daily Living (ADLs) [12]. Excluding privacy-sensitive and kitchen/bathroom-related tasks, and adding "relaxation" as leisure, we selected six representative tasks for the study (Fig. 8).

Before the session, participants received written instructions outlining six tasks and specifying, "*Please do them in an order that follows your recollection of how you did these kinds of tasks recently at home.*" There was no fixed task flow or time limit; participants were free to switch, combine, or pause tasks as they would naturally at home. This flexible structure was essential for capturing natural lighting behaviors and maintaining the study's ecological validity.

After providing informed consent, participants were guided to the study room and shown how to operate their assigned light fixture. Intervention participants used a laser-pointer remote for prototype movement and voice commands for lighting control, while control participants operated the desk lamp with its button. Considering the desk lamp was a familiar household object with intuitive adjustability through manual repositioning, we only demonstrated its button-based light control rather than its movement. All participants were told, "*You're free to move or use anything in this room*," ensuring consistent instructions across groups.

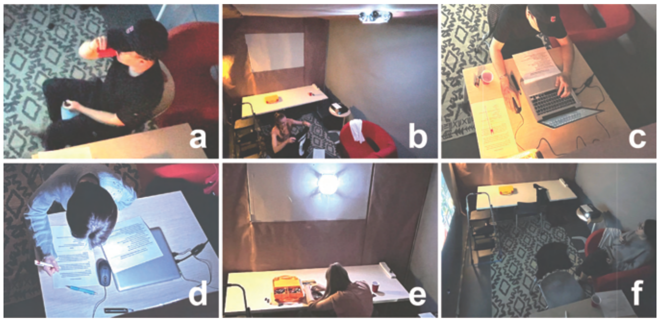

Fig. 8. The six tasks of our user study: (a) Eating, (b) Chores, (c) Computer Work, (d) Paperwork, (e) Hobbies, and (f) Relaxation.

	Intervention Group		Control Group	
Assessment Items	**Mean**	**SD**	**Mean**	**SD**
Light Overall	4.62	1.80	2.46	1.33
Artificial Light	5.23	1.64	2.38	1.33
Reflection or Glare	4.85	1.72	4.31	1.84
Mean Score	**4.90**	**1.26**	**3.05**	**1.04**

Fig. 9. Perceived comfort assessment (1=Unsatisfactory, 7=Satisfactory)

	Intervention Group		Control Group	
Assessment Questions	**Mean**	**SD**	**Mean**	**SD**
How much does the light module help you move through the tasks?	3.92	0.86	2.62	1.19
How much does the light module make you feel you have control over the space?	4.08	1.04	2.46	1.33
How much does the light module make you feel confident about performing the tasks?	3.92	0.64	2.46	1.13
Mean Score	**3.97**	**0.66**	**2.51**	**1.12**

Fig. 10. Perceived control assessment (1=Not at all, 7=Extremely)

The researcher then left the room, began video-recording via a mounted camera, and operated *Light Everywhere* remotely via WoZ from concealed positions to minimize observer effects. Participants were only approached if they requested help or indicated they had completed the tasks. After the session, participants underwent a 10-minute semi-structured interview and a post-questionnaire.

C. Data Analysis

Our dataset included post-questionnaire responses, interview transcripts, and session video recordings, with participants labeled as P1 to P13 (intervention) and P14 to P26 (control). The study focused on three dependent variables: perceived comfort, perceived control, and spatial utilization. Comfort and control were measured via targeted questionnaire items (Fig. 9, Fig. 10), while spatial utilization was assessed by analyzing participants' time distribution across room areas in the recordings (Fig. 11). Interviews were transcribed using *Otter.ai* and manually reviewed and verified afterward. Combining deductive and inductive coding approaches, we categorized responses under the three variables, with emerging themes identified through iterative grouping.

For video analysis, we adopted an exploratory approach to examine behavioral patterns related to spatial utilization and light interaction. 19 behavioral codes were defined based on observed actions: 12 events (e.g., "*switching lighting mode*") and seven states (e.g., "*staying on the sofa*"). A single researcher applied the coding protocol to analyze all recordings for consistency, recording event occurrences, state durations, and contextual details for cross-group comparison.

IV. Results

A. Perceived Comfort (RQ. 1a)

To assess perceived comfort, we used the *Light* section of the *Indoor Environmental Quality Questionnaire* from the *OFFICAIR* study [13]. Fig. 9, resulting from the question, "*How would you describe the indoor conditions in the experimental environment during the study?*" shows significantly higher satisfaction in the intervention group, $t(24) = 4.0589$, $p < .001$.

Nine of 13 intervention participants described *Light Everywhere* as "*comfortable*," "*convenient*," or "*effortless*." P2 noted it felt "*nice and comfortable*," while P4 found it "*convenient*" as "*you don't need multiple lights around the room, just one.*" P12 also highlighted its ceiling-mounted flexibility as "*more human ergonomic.*"

In contrast, four control participants reported discomfort using the desk lamp. Three experienced eye strain from direct light exposure, with P22 describing it as a "*spotlight*" that just "*came towards your face*" and P24 calling it "*intense but not distributed properly.*" Despite identical light modes and diffusers, the desk lamp was reported to have more discomforting factors than *Light Everywhere*.

B. Perceived Control (RQ. 1b)

To measure perceived control, we adapted the *Perception of Control* survey from the *SORT* project derived from the *NIOSH Generic Job Stress Questionnaire* [7]. Fig. 10 captures the results following from the prompt, "*Please answer the following questions based on how you have completed the six tasks just now*." Here, the intervention group reported significantly higher perceived control over their environment and tasks, $t(24) = 4.0583$, $p < .001$.

Ten of 13 intervention participants affirmed an increased sense of control during interviews, contrasting *Light Everywhere* with their home lighting. P3 stated that instead of being forced to work in the living room due to poor bedroom lighting, "*I can choose how to use the space because the light is movable.*" P9, who frequently repositioned their floor lamp for different activities at home, appreciated the ease of moving *Light Everywhere* because "*I didn't have to think about whether I could put it here or plug it in there.*"

However, the other three "intervention" participants criticized the robot's delayed responses and unexpected movement, with P12 calling it "*creepy*" and P11 feeling "*vulnerable.*" In the control group, six participants reported a lack of control, and 12 desired a more adjustable lighting system.

Video analysis revealed the intervention group adjusted lighting more frequently. All 13 moved the light fixture (M=3.77 times, SD=2.17), compared to only 3 in the control group (M=1.67 times, SD=1.15). Similarly, 11 interven-

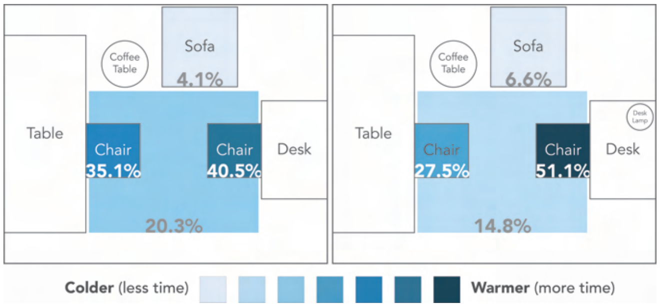

Fig. 11. The heat maps showing the composition of time spent in each area: (left) the intervention group, and (right) the control group.

tion participants changed lighting modes (M=4.18 times, SD=2.86) versus 7 in the control group (M=2.14 times, SD=4.16). These results suggest that, by enhancing participants' perceived control, *Light Everywhere* encouraged frequent lighting adjustments.

C. Space Utilization (RQ. 2)

To evaluate *Light Everywhere*'s impact on spatial utilization, we heat-mapped where participants spent time across the room (Fig. 11). Room corners were excluded due to scant occupation.

While study completion times were similar between groups (intervention: M=1625.33s, SD=377.83; control: M=1639.42s, SD=551.23), spatial utilization differed. The control group, constrained by the desk lamp, spent 51.07% (M=837.33s, SD=667.56) of their time in the desk chair and 27.52% (M=451.17s, SD=358.73) in the table chair. The intervention group exhibited a more balanced distribution, with 40.45% (M=657.43s, SD=153.79) at the desk and 35.10% (M=570.57s, SD=536.38) at the table, with increased movement in the central area and reduced sofa use.

Interviews further highlighted the potential of novel spatial interactions with *Light Everywhere*, including increased use of underlit corners and often ignored ceilings. P12 noted realizing the possibility of ceiling interaction beyond "*placing stuff on the ceiling for a very long time.*" These findings suggest *Light Everywhere* promoted flexible spatial choices, reducing constraints of fixed lighting.

V. Discussion

Results indicate that our robotic light fixture enabled participants to adapt their environment to various tasks. P3 stated, "*With Light Everywhere, I could use the space the way I wanted to, not in a way I had to*." Despite similar task completion times, the intervention group reported a greater sense of comfort and control consistent with prior research on housing flexibility [1], [2]. The following section examines behavioral changes induced by *Light Everywhere*.

A. Unconscious Tolerance for Unsatisfactory Lighting

The control group passively accepted suboptimal lighting, perceiving it as fixed and unalterable. This tolerance was evident in their use of the desk lamp: no participant attempted to move it from the corner where it was initially placed; only three moved it slightly, while six never touched it. However, the control group reported significant dissatisfaction with lighting (Fig. 9), indicating reluctant tolerance.

When asked why they did not adjust lighting, control participants cited unawareness, with P26 stating, "*It didn't even cross my mind,*" and P22 adding, "*I felt I had to tolerate it.*" Despite being informed they could rearrange the space, the control group viewed lighting as a fixed factor to endure. In contrast, all intervention participants actively repositioned *Light Everywhere*, showing no tolerance tendency.

Our findings suggest that people may be unknowingly tolerating suboptimal environments–that movable light fixtures *enable us* to better adapt our spaces to evolving needs.

B. Affordance-Driven Invitation for Adaptive Behaviors

Beyond reducing passive tolerance, *Light Everywhere* encouraged adaptive behaviors that improved task experience. Its wheeled design visibly afforded mobility, signaling to occupants to adjust the lighting. As Withagen et al. proposed, affordances function as "invitations" for certain behaviors [14]. Our findings suggest the robotic lighting "invited" participants to optimize lighting for comfort and control.

This behavioral shift was evident in lighting adjustments. Despite both groups reporting eye strain caused by the direct light, only one control participant moved it out of sight, compared to nine in the intervention group. All 13 intervention participants repositioned the fixture, and 11 changed lighting modes, compared to only 3 and 7 control participants, respectively. These findings suggest that the intervention group's increased comfort and control might arise from greater engagement in experience-enhancing actions. Through adaptive interaction, *Light Everywhere* reimagines lighting as a responsive partner in domestic life.

C. Future Applications

Light Everywhere's benefits and potential uses:

1) Detail-Oriented and Hands-Occupied Tasks: Eight participants recognized the robot's utility in detailed tasks such as locating objects (P13), performing surgery (P6) and "*anybody doing hands-on tasks*" (P9) like plumbing. Seven participants emphasized *Light Everywhere*'s hands-free adaptability in multi-task environments: P9 envisioned dynamic lighting for kitchens, while P1 proposed its use in art studios, where the light could follow users across workstations.

2) Social and Emotional Interaction: An unexpected finding was *Light Everywhere*'s potential as a companion. Users often attribute human or pet-like characteristics to robots, an anthropomorphization of the human-robot relationship [15]. This phenomenon was observed in our study, where four participants referred to the prototype as "*him*," and two engaged in conversation with it. Additionally, in 89.13% of voice-command interactions, participants looked at the robot—even though visual attention wasn't required—suggesting they may have perceived it as sentient or socially aware.

Similarly, participants perceived *Light Everywhere* as a welcomed social presence. P3 described the robot as "*nice to have someone*," attributing to it human-like traits–characterizing it as "*cute*," "*lively*," and "*listening to me*." Consistent with prior research demonstrating robots' ability to boost mood and well-being [16], these findings suggest that *Light Everywhere* was recognized by some participants as a companion, reducing feelings of loneliness even in the duration of this one-person study. Future work may explore robotic lighting's potential applications to alleviate feelings of isolation.

3) Energy-saving Potential: Five intervention participants discussed *Light Everywhere*'s energy-saving potential. P12 stated, "*If we are given autonomy to control the ceiling lighting, we don't need as much lighting as we do now.*" P8 also noted its mobility could prevent them from forgetting to turn off lights "*if he (the movable light fixture) travels with me.*" These insights suggest that *Light Everywhere*, a single movable light fixture, has the potential to replace multiple static light devices towards a more energy-sustainable home.

4) Future of Autonomous Robotic Lighting: While participants acknowledged the potential benefits of autonomous lighting, many expressed hesitation, reflecting broader societal concerns about robotic autonomy [17]. However, the strong negative perception recorded in early surveys (Fig. 4, 5) was less evident among intervention participants. P7 suggested this shift stemmed from firsthand experience: "*Before this experiment, I never experienced so much control of the light, so I never thought I needed it, but after I experienced that, I feel this feature is really nice to have. I would say the automatically moving light is the same thing.*" Our findings suggest that resistance may stem from unfamiliarity, underscoring the value of experiential research in evaluating autonomous systems.

VI. Conclusion and Future Work

This paper introduces *Light Everywhere*, a wall- and ceiling-climbing robotic lighting fixture that brings spatial flexibility to domestic environments. Through field deployment and controlled studies, we demonstrate that the system enhances user comfort, control, and spatial efficiency, while reducing passive acceptance of suboptimal conditions. By enabling users to reposition light and adapt its behavior to changing tasks, *Light Everywhere* fosters an active, embodied form of environmental interaction.

Future work will enhance prototype fidelity with commercial lighting, automated interaction, and stable mobility on non-magnetic surfaces. Long-term home studies will capture real-world use and reduce novelty effects.

This paper contributes to human-robot interaction by reframing lighting as a site of dynamic, user-driven collaboration between people and autonomous systems. It highlights how robotic fixtures can move beyond task execution to become partners in shaping lived experience. Moreover for HRI, this research offers a concrete example of how human-centered robotic design can support everyday adaptation, encourage agency, and integrate seamlessly into domestic life. We position robotic lighting as a promising frontier for situated, socially aware, and context-responsive HRI in the home.

Acknowledgments

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