Who Should Hold Control? Rethinking Empowerment in Home Automation among Cohabitants through the Lens of Co-Design

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ABSTRACT

Recent HCI research has highlighted home automation's potential in providing residents with technology-enhanced domestic autonomy. However, in the cohabitation context, the prevalent solutionist paradigm of automated systems introduces challenges to non-experts, paradoxically marginalizing specific members. This paper reports a co-creation initiative involving cohabitants, exploring a new understanding of empowerment in home automation. Participants collaborated to construct Trigger-Action Program (TAP) schemes using card-based tools during workshops. Our findings showcase how cohabitants engaged in collective ideations and embodied different negotiation patterns, which reveals the significance of more perceptible and participatory design. We frame home automation as "problematic co-design", arguing the universal overlook of collaborative resources. Furthermore, we examine how automation systems act as obstacles and sources of empowerment through the co-design lens. The paper concludes with pragmatic recommendations for designers and researchers, emphasizing the need to foster contestability for cohabitants in the evolving home automation landscape.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; **Empirical studies in collaborative and social computing**; **Ambient intelligence**.

KEYWORDS

Co-Design, Home Automation, Empowerment, Card-Based Tool, Smart Home, Cohabitant

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1 INTRODUCTION

In recent years, the HCI community has increasingly focused on the sustainable and equitable adoption of technology within households. The technology-augmented capabilities have significantly contributed to the well-being of many by offering automated and scalable smart home experience [26, 28]. Home automation [10, 42], as a practical extension of these themes, has been widely accepted by many households, catering to consumers interested in technology-driven domestic lifestyles. Within the realm of it, Trigger-Action Programmes (TAPs) have become one of the most popular home automation configuration paradigms adopted by smart home vendors, which embody the idea of Do-It-Yourself concepts and autonomy in domestic technology [60]. Often designed into a graphical interface, a TAP allows users to use the "if a trigger occurs, then an action performs" syntax as a conditional control scheme (See Figure 1 for two intuitive examples of TAP schemes). Residents can integrate expected conditions of a batch of smart appliances or environmental data, such as weather and time, into a scheme in order to make devices automatically execute the operations under certain conditions according to their preferences. Some enthusiasts often regard this kind of rule-based approach [67] as the power and possibility to embrace people's ideal family life, which is perceived as narratives around empowerment through extending domestic capabilities and enhancing environmental control [11, 42].

However, this technology-driven empowerment is not equally accessible to every member within a household [34]. Whilst research

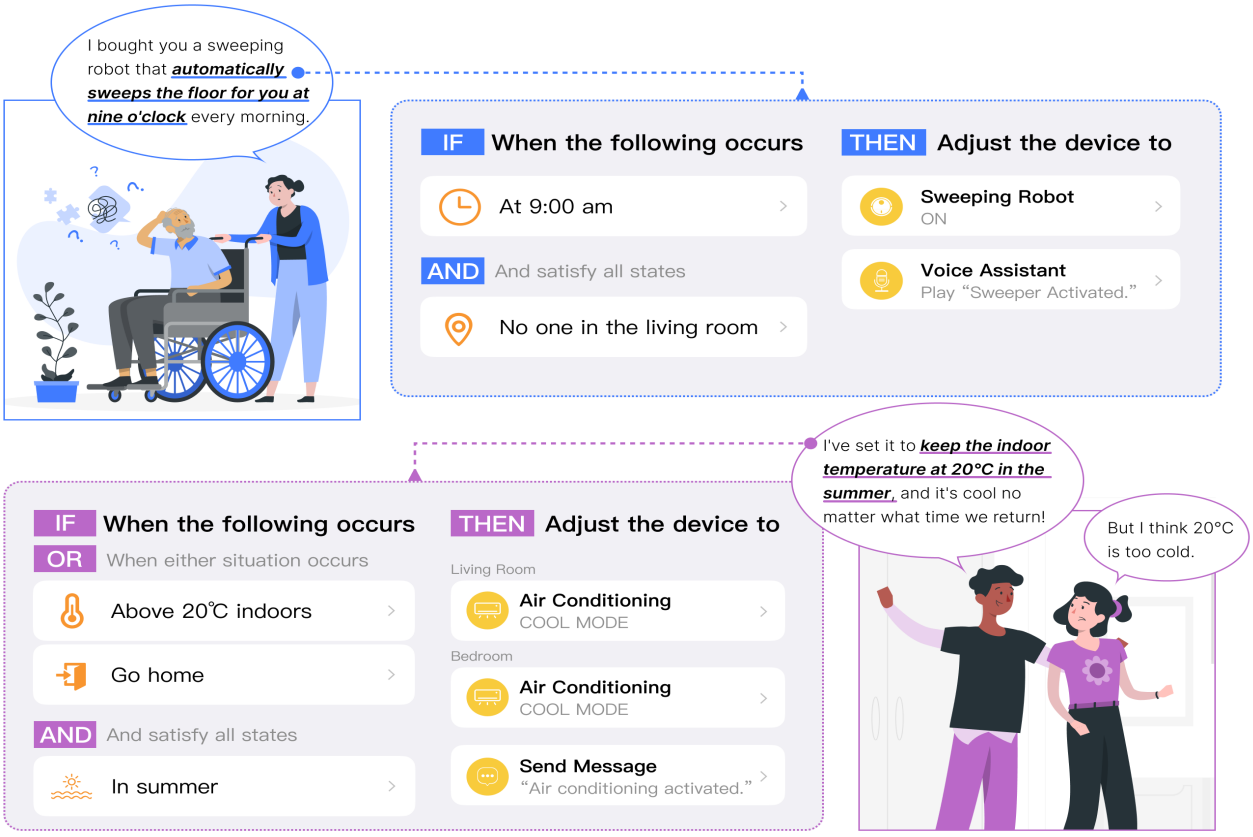

Figure 1: Two Examples of TAP Syntax by Co-habitants in Shared Space.

related to TAP has made significant efforts to improve accessibility for including users with varying levels of technological proficiency [4, 67], home automation is still inevitably criticized as it appears to marginalize some of the cohabitants including non-technical groups or those who occupy disadvantaged positions in domestic power dynamics [17]. For instance, prior work has indicated the troubles of homemakers [15] in home automation usage, as they may lack technical expertise, hindering their ability to engage with these systems effectively. This issue extends to technologically inexperienced children [64]who are often in a subordinate role in family dynamics, thus ignoring their need to access home automation systems. Older individuals also face significant barriers in adapting to automated environments, resulting in refusal to use or abandonment of products [11, 12]. These exclusions to the beneficiaries paradoxically exacerbate domestic power imbalances despite empowering intentions of automated technology. However, despite the apparent contradictions, there is still a lack of understanding of the obstacles to empowerment stemming from the design paradigm of home automation in the context of cohabitation.

Cohabitants, such as families or roommates living in the shared living space, are often diversified in backgrounds and social roles, which signifies varying needs for home automation settings [15, 31]. However, conducting practices related to home automation to facilitate negotiation for demand differences is typically not at the forefront of relevant studies. Moreover, the empowerment related to home automation primarily stems from an interventionist intention with extrinsic technological-augmented benefits rather than expecting enhancement with bottom-up approaches, which shows inconsistency with the ideas around empowerment and technological democratization [6, 25]. As such, the work supporting empowerment in home automation must first be approached from a social-technical perspective to associate stakeholders with automated systems. Our work recognized the ideological parallels between home automation and the co-design approach in HCI, especially the common vision for engaging heterogeneous stakeholders in co-creation and empowering non-experts [44, 65]. However, it is relatively seldom that this approach is adopted for probing political matters related to home automation or extends into new pragmatic approaches for refining current home automation systems.

In this study, we reported a co-creation initiative involving co-habitants, exploring what implications we could gain on "empowerment in home automation" within the cohabitation context, and how designers can support empowerment in the realm of home automation. We ground in a qualitative approach and employed

a card-based co-design strategy to understand and address the marginalization challenges within home automation. Our work is positioned to foster democracy in domestic technology usage stemming from reconsidering the role of home automation, the connotation of empowerment, and the corresponding responsibility of designers, rather than providing specific card-based tools as add-ons. It's worth pointing out that we used the cards and other materials as a designerly strategy for pursuing exploratory, open-ended insights (as discussed by design-oriented HCI research such as [22] and [14].

We designed and conducted five co-design workshops, and invited 20 stakeholders with various demographics, technical abilities, experience in home automation, and living conditions to create TAP schemes using cards and other shared materials. Our findings uncover the potential of cards as a meaningful alternative to facilitate cohabitants in automation ideation, as well as serving as a "power probe" for amplifying the disempowerment-related problems in the materials and practices of current home automation, highlighting the interactions around cohabitants, and facilitating small politics among different cohabitants. Through this, this paper contributes 1) Attributing the failure in empowerment to the faultiness of home automation as a "problematic co-design process" that overlooks establishing collaborative resources for dealing with differential demands from cohabitants; 2) Highlighting three aspects of home automation system design, which — consider shared material and processes — are identified as obstacles and sources of empowerment in co-design defined by Zamenopoulos et al. [75]; 3) Rethinking the implication of empowerment in home automation and call upon researchers to act as "facilitators" of empowerment and pay attention to power dynamics and social norms within shared spaces in related studies, which provides a novel perspective for diversity and technological democratization within households.

2 RELATED WORK

2.1 Evolving Perspectives on Home Automation

Home automation was initially seen in the HCI as a technological-led benefit surrounding the domestic Internet of Things (IoT) technologies adoption. Early work on home automation is motivated by the vision of extending the technological advancements from being "embraced by a small community of affluent and technically proficient early adopters" [41] to a broader range of communities [11]. The literature on trigger-action programming [67], a method that empowers end-users with low programming capacity need to accomplish home automation based on "if-then" instructions, has demonstrated insights on more scalable and user-friendly modalities [8, 11, 67, 76], stimulating discussions on how to enable non-programmer residents with more autonomy in automation design and turn complex control schemes for devices into executable rules [18]. Beyond exploring usability, more research was keen on expanding the applicability of home automation through interaction, showcasing future-oriented technology-augmented approaches to home automation control methods, including but not limited to graphical synthesis languages [35], drag-and-drop interfaces [33], augmented reality [3], and gamification elements to introduce playfulness [32].

Despite the initial intentions of universalizing the "supremacy of the geek" and focusing on households, there have been numerous criticisms of home automation for its less-than-ideal benefits in shared living spaces such as homes or apartments. It is, therefore, perceived as a part of the challenges related to technology appropriation in a domestic context [72], which is evident in studies on the taxonomies of home automation users. For instance, Woźniak et al. [73] identified the differentiation of user roles within smart home ecosystems, which is divided into "administrators," "active users," and "passive users." They emphasized that some "non-administrators" are constrained in their autonomy to explore and use smart home technology due to system complexity. Koshy et al. [34] adopted a more illustrative classification, referring to the family members who predominantly contribute to automation schemes as "pilot users" and those who only utilize the systems as "passenger users." They revealed the prevalence of these polarized user roles, attributing them to familial roles and knowledge gaps that limit user engagement. From the perspective of technological democratization, these obviously challenged whether more stakeholders can become beneficiaries of home automation in a more technology-augmented future.

Other studies have begun to address the social factors around the home and home automation, in order to contribute to the interpretative view on technology appropriation among habitants with diverse family identities, social roles, genders, and technical capability [15, 62], as well as communication and negotiation patterns among members regarding technology use [27]. However, despite these initial acknowledgements of the social challenges behind home automation, a deep-rooted techno-solutionism still sparks the dilemma of "empowering more people" versus "one size does not fit all." We view this challenge as an opportunity to rethink home automation ideologically as a co-design process that aims to construct automation schemes with collective creativity. We intend to break the traditional triadic relations of the designer (researcher), household members, and home automation systems in the design process, and thus explore how to enable home automation systems as tools to support cohabitants as "experts of his/her experience" [52] in envisioning the lifestyle they desire.

2.2 Empowerment in Home Automation: for Contestability

Whilst the discourse surrounding empowerment related to home automation has become a potential consensus in HCI research [36, 37], suggesting the extensive benefit from technological advancement to families; however, the notion of empowerment within this context remains ambiguous. A significant portion of home automation studies are devoted to liberating productivity and providing more life choices for people at home by introducing novel automated technologies or designs, which can be referred to as "empowerment with home automation". This paradigm is considered as an alignment with the initial intentions of home automation that attach technological progress to end-users for functionality or experience improvement [10]. As such, studies in this vein commonly adopt the notion that regarding individuals as empowered when their initiative is strengthened through more natural interactions

[21, 37, 43, 54], or when they gain more autonomy through automated systems [48, 50, 63].

While many themes in HCI research are developed with this paradigm contributing to well-being at home, its inherently top-down nature contradicts the essence of empowerment. Some criticisms related to empowerment and technological democratization can be seen as the interpretation of the issue, such as noted by Cristiano Storni that "thinking of designing something to empower the user after design is however problematic and presents itself as an oxymoron" [61]. Cazacu et al. [13] argued that empowerment is rooted in understanding the power dynamics behind citizens and communities, and thus, it creates conditions for problem-solving. Ironically, if examining research related to home automation from the standpoint of considering understanding social implications within families as a premise for empowering intentions, many works seem to contradict this notion. This is attributed to the grounding on techno-solutionism [1], which lacks a social-technical perspective of considering problems lacing home automation as a "wicked problem" [16].

Despite the inevitable paradox of empowerment that suggests new power imbalances may be introduced by designers [40], it is crucial to reconsider how to enable home automation for empowerment and foster the paradigm shift from "empowerment with home automation" to "empowerment in home automation" in HCI. This shift emphasizes understanding the social-technical implications so as to give attributes to home automation as enablers of power dynamics improvement.

Whilst there are substantial divergences in the definition and interpretations of empowerment within different contexts in HCI literature [40, 55], we highlight the understanding of the "power" related to domestic technology use as fundamental to discuss the "empowerment in home automation". The power dynamic is rooted in the household identified as a complex social, economic and political arena by Silverstone and Hirsch [57]. From such a perspective, as elucidated in the previous theme, various factors such as technological proficiency, physiological levels, and social identities shape disparities in the exercise of power in using home automation technologies. The theory of domestication [20] also underscores the dominance of household technological power when someone brings a smart appliance to the space by the influence of "a culture of consumption".

As such, we take the aligned understanding of empowerment in home automation from the assertion of activists, that democracy is built on a "radical pluralism with the ability to contest" [46]. The empowering practice is "by designing for contestability" [68], which contextually means different individuals are granted equal power to understand, shape, and challenge the decision-making during home automation ideation and further use. Indeed, the issue of contestability in domestic technology usage is potentially pervasive in HCI studies, extending beyond home automation. However, it is crucial to consider how to support the contestability of technological use in design for empowerment from a pragmatic perspective rather than only staying on advocacies.

Our work provides a novel direction to consider empowerment in home automation, and even more broadly, in broader collaborative domestic technology by enhancing residents' contestability as how co-design practices usually organize diverse participants with materials: The home automation system, as the scaffold of the co-creation process for all members, is advocated as a platform that promotes negotiation and supports habitants in exerting greater influence on automation creation. This positioning expects habitants to equally impact decisions with a more inclusive approach accommodating differences such as gender, occupation, and technological capabilities. Additionally, considering the role which design should play in different power dynamics within families and other cohabitations, it reveals the importance for designers and researchers to reflect on the interventionism remaining in design for empowerment, which to a different extent exists against the diverse inherent power ecosystem.

2.3 Card-based Tools for Empowerment

Card-based tools as a co-design technique have been widely adopted in empowerment-related topics [49]. Considering the configurability, shareability, and engagement of cards, it is often utilized to interlink technology-augmented objects, structured information, and diverse stakeholders in HCI studies, for fostering more autonomous and equitable user participation [38, 47, 71]. However, in the domains related to SHT, home IoT, and home automation, despite card-based tools and toolkits being designed as alternative metaphors around smart devices, users, and other usable materials, their use is mostly limited and considered a promising source of provocativeness or seen as a new modality for tangible programming.

For example, Mora et al. [44] proposed Tiles as a set of card-based tools for supporting non-expert users in IoT ideation, which showcased a wide range of themes discussed in co-design. They uncovered how card-based tools act as triggers for creativity and reflection, assisting participants in idea generation during workshops. Whilst the dominant role of some participants in the ideation process was mentioned in their findings, their discussions only focused on the rule-making processes. Although this revealed power imbalance in co-creation has not received significant attention, it implies the potential of card-based tools to explore socio-factors within co-design and community-based DIY technology. Additionally, Tada and Tanaka [65] explore the use of tangible programming in paper card form to enable more perceptible control of smart devices, making user participation in home automation possible through pen-and-paper as a medium.

While these activities with card-based tools provide spaces for collaborative participation in home automation for various groups, particularly non-experts and marginalized users, it is seldom that studies simultaneously highlight the probing implication of card-based tools which, as a fuzzy but legitimizing alternative framing to the present, criticize current design paradigm on the issues related to empowerment. Whilst it is often ambiguous [39] on how researchers explain probes, the implicit intentions are consistent on "pushing practice in new directions as opposed to locking it down into an off-the-shelf method" [14].

Beyond serving as a more perceptible visual metaphor supporting the discussion and negotiation during automation ideation between cohabitants, in our work, we also regard the card-based tool as a "power probe". This means the stories among cohabitants

around the use of home automation would be unfolded in the co-design, which allows researchers to explore social factors around multi-user smart home power dynamics (i.e., those emphasized by [19, 29]) with an open-ended approach. Specifically, the card-based tool would amplify the disempowerment-related problems in the materials and practices of current home automation, highlight the interactions around cohabitants, and facilitate small politics among different cohabitants in home automation usage towards more democratic and inclusive actions, which are all emphasized by Çerçi et al.[14] as critical nature of probes.

However, despite the promising value of the card-based medium as a possible interface for home automation control, it is essential to clarify that we see our card-based tool as a critique resource to the prevalent TAP system rather than presenting an inevitable or specific design solution. It embodies our attitude towards empowerment in home automation that calls for considering the contestability of different residents in home automation use and ideation and providing subverting design practices in more perceptible and collaborative frames.

3 METHODS AND RESEARCH PROCESS

Building upon the discussion of prior work, two key issues are identified around the empowerment in home automation: (1) the power imbalance during home automation ideations due to cohabitants' backgrounds and roles, and (2) deficiencies of home automation systems hindering empowerment due to top-down design. In response, we designed a set of card-based tools and workshop materials to foster a novel co-design experience for home automation ideation in a series of workshops. Participating households are expected to be different in ages, occupations, technical capacities, experience with smart home technologies and home automation, living conditions, and social roles within living spaces. We are specifically interested in how to create a more empowering process for heterogeneous users in home automation empowerment. Additionally, we hope to offer pragmatic reflections on the source of obstruction from current TAP on technological democratization and empowerment, with potential avenues for change identified.

This research employed a qualitative approach based on co-design workshops. The habitants were invited to a fully equipped smart home living lab [74], as shown in Figure 2, and they were provided with ample time for independent room tours and device trials before the workshops commenced. Workshop assistants were also available to explain the space and devices when needed. The rationale behind this process was to establish a connection between the residents and their surroundings, aiding them in quickly attaining a comfortable, homely state. Meanwhile, participants associated the smart home or automation setups in the lab with their own living environments, facilitating context-relevant reflections during the workshops. Additionally, this environment supported the subsequent understanding of device information on the cards, particularly the functionalities of various smart home devices.

3.1 Design of Card-based Tool

The primary task of the card-based tools was to serve as shared materials reflecting the traditional home automation ideation process in co-design. This necessitated designing the cards to strike a balance between being provocative and pragmatic. On the one hand, the cards needed to encourage people to innovate in their ideation, stimulate collaboration and negotiation among cohabitants, and offer open-ended opportunities for researchers to gain new insights related to the shortcomings of traditional home automation systems or the social characteristics of participants. On the other hand, the card content had to run parallel to participants' home automation usage experiences and therefore be structured. This helped prevent the residents from proposing over-unrealistic ideas and ensured the practicality of the research conclusions.

In our endeavor to develop a suite of card-based tools tailored for co-designing home automation schemes, we draw inspiration from the work of Mora et al. [44]. Meanwhile, for the pragmatic design of cards content, we investigated various smart home apps such as Mi Home[1], Home app[2], and Home Assistant[3], and identified two common and core elements in home automation:

(1) Devices and environmental factors: This includes devices capable of executing automation rules and environmental information that serve as triggering conditions. Our device selection process involved choosing commonly used smart home products based on literature research and experiential knowledge. We distilled the essential functions of these devices, as outlined in Table 1. Environmental information comprises natural environmental indicators and people's spatial information, typically obtained and transmitted through local sensors or third-party internet service providers such as clocks or weather. Table 2 illustrates the environmental information selected, all of which is readily available in existing smart home apps.

(2) Logical rules: the rules based on TAP that connect devices, their respective functions, and environmental factors through "if-then" logic. To articulate this logical structure distinctly, we devised stickers to establish connections (*section 3.1.2*).

The habitants were then encouraged to employ these cards and stickers in constructing automated solutions (*section 3.1.3*). Additionally, to support the collaborative co-design, where participants gather in a circular arrangement, the cardboard design facilitates both independent scheme creation and seamless communication and idea exchange (*section 3.1.4*).

3.1.1 Cards. As visual affordances of devices and conditions within automation schemes, cards share the same dimensions as standard playing cards. They are designed with a special material on the card surface to allow repeated writing and erasing. The cards are divided into three types: Device Cards, Environment Cards, and Custom Cards, as shown in Figure 3.

The Device Cards in blue feature smart home devices available in the living lab. The main content of the cards includes an image of the device and its corresponding functions. Additionally, each card displays a device number and its corresponding room, aiding participants in locating the devices in the living lab through its plan on the cardboard. Devices of the same type but placed in different rooms, such as air conditioners in the living room and bedroom, are represented on separate cards and can be distinguished by their numbering and room placement.

[1] https://www.youtube.com/watch?v=OAlhfvud9ts
[2] https://www.apple.com/home-app/
[3] https://www.home-assistant.io/

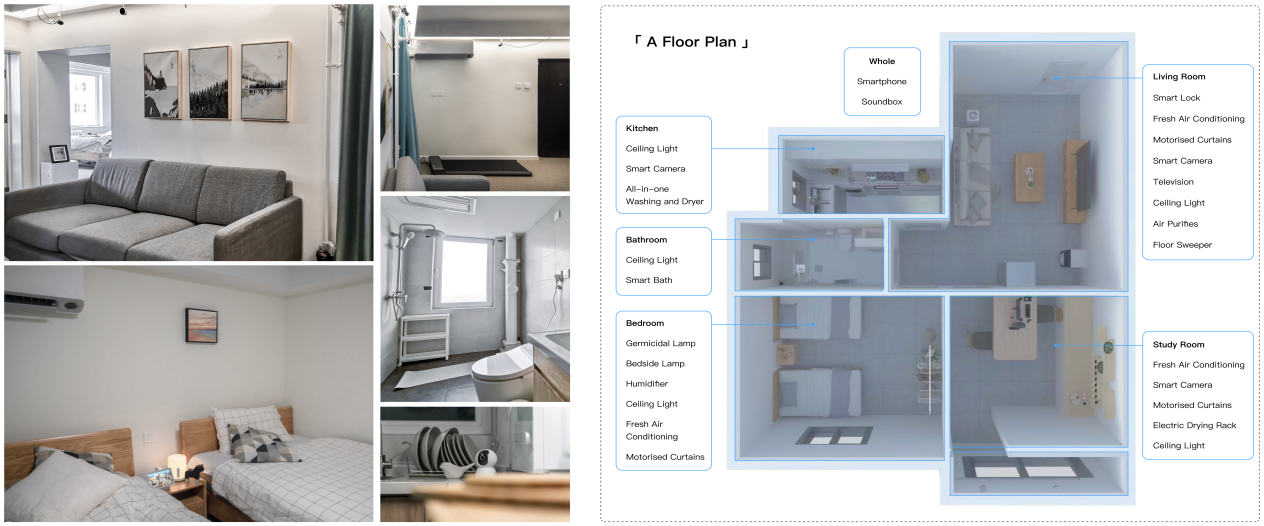

Figure 2: Living Lab Environment: (a) On-site Photographs; (b) A Floor Plan with Smart Home Pproducts

Table 1: Device Cards Content

Name	Location	Function
Soundbox	Whole	On / Off
Smart Camera	Living Room / Study Room / Kitchen	Sleep Mode / Activation Mode / Video Recording / Stop Recording
Smart Lock	Living Room	Detecting Door Open / Detecting Door Closed
Fresh Air Conditioning	Living Room / Study Room / Bedroom	Cooling / Heating / Dehumidification / Ventilation / Sleeping / Off
Motorized Curtains	Living Room / Study Room / Bedroom	Draw the Curtains / Close the Curtains
Television	Living Room	On / Off
Ceiling Light	Living Room / Study Room / Bedroom / Kitchen / Bathroom	On / Brightness / Color Temperature / Off
Bedside Lamp	Bedroom	On / Brightness / Color Temperature / Off
Germicidal Lamp	Bedroom	On / Off
Humidifier	Bedroom	On / Off
Air Purifies	Living Room	On / Off
Floor Sweeper	Living Room	On / Off
Electric Drying Rack	Study Room	Rise / Lower / Turn on Lighting / Turn off Lighting
Washing and Dryer	Kitchen	Self-Clean / Wash / Spin Dry / Dry / Off
Smart Bath	Bathroom	Lighting / Heating / Ventilation / Defogging / Off
Smartphone	Whole	Receiving Message Alerts

The Environment Cards are yellow and provide various natural environmental indicators and people's location information that are able to be obtained in the living lab, such as temperature, humidity, or individual positions, as the primary content. In the realistic data collection, some natural environmental indicators, such as indoor CO_2 concentration and PM 2.5 concentration, are typically captured by IoT sensors indoors. Other global information, such as time and regional temperatures, is usually sourced from the internet and accessed by the automation system. Information related to people's positions often comes from GPS systems on phones or indoor sensors. However, considering that unfolding these sources of information could potentially distract the residents from their primary task of exploring social factors and cooperative ideation

Table 2: Environmental Information Cards Content

Environmental Information	Description	Examples
Temperature	Indoor temperature of a room	Above 26°C, below 20°C
Humidity	Indoor humidity of a room	More than 80%, exceed outdoor humidity
CO_2 Concentration	Indoor CO_2 Concentration of a room	Indoor CO_2 Concentration of a room
PM2.5 Concentration	Indoor PM2.5 Concentration of a room	More than 10 ug/m^3, exceed appropriate concentrations for humans
Human Movement / Place	Position of people in the house / Distance between a man and his house	In the living room, 50 meters from home
Weather	Including but not limited to outdoor temperature, humidity, sunrise and sunset, and precipitation	Raining, sunset
Duration	Length of a period of time	3 hours, 15minutes
Time	At a certain point in time	8:00am, 18:00pm

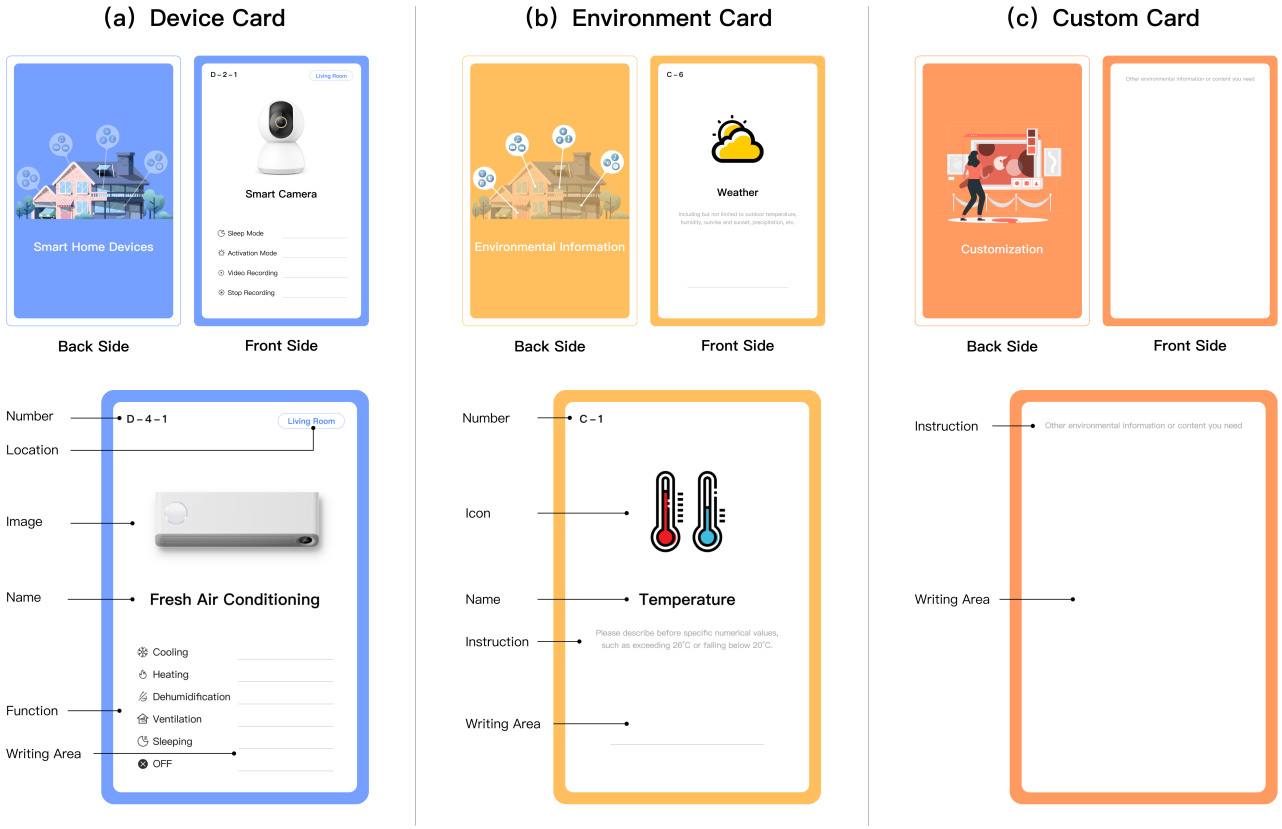

Figure 3: Front and Back Design, and Templates Presenting on the Front of (a) Device Card, (b) Environment Card, and (c) Custom Card

in the experiment, these relevant sensors are not presented on the cards.

Nonetheless, we also provide the residents with supplementary tools - orange Custom Cards that are blank for people to add content beyond what the two types of cards offer.

3.1.2 Stickers. Stickers were designed to represent the logical relationships used by TAP, including "IF" and "THEN" that indicate triggers and corresponding actions, as well as "AND" and "OR" as connectors. Stickers serve as facilitators for participants, allowing them to flexibly attach them between device cards and environment cards. The cards will be connected by stickers physically and logically to form rule-based automation schemes, as depicted in Figure 4.

3.1.3 Strategies for card scheme generation. Participants select device cards and environment cards as trigger conditions for their schemes, followed by choosing device cards for executing actions, using stickers to indicate logical relationships between cards. Specific states or functions of the devices, as well as details of environmental information, can be chosen or supplemented by participants with pens based on the information provided on the cards. For example, if a participant wants to create a scheme like "If the living room ceiling light is on or it's after 6 PM, and at the same time the temperature is above 26°C, set the living room air conditioner to cooling mode and set the temperature to 24°C", as illustrated in Figure 4, they can select the "time" and "temperature" environment cards, as well as the living room ceiling light and air conditioner, and mark the corresponding functions or write down the desired temperature value. Logical relationships are also represented using various stickers, with the logical distributive property indicated by circular stickers being fully adhered or half adhered.

3.1.4 Cardboard. The cardboard was presented as a shared interface to hold the cards and other shared materials, facilitating the demonstrations and dialogues on the basis of equality among the four residents throughout the workshop. It is divided into four distinct functional areas, including (1) Four color-coded scheme design areas for the four residents to place their card schemes and annotate relevant themes with sticky notes. (2) Two material tool placement areas designated for tools such as sticky notes, pens and Device Cards. (3) A shared card placement area positioned in the middle, allowing all the residents to take Environment Cards, Custom Cards and stickers. (4) A floor plan of the living lab displaying the functions of different rooms and the smart home devices within them. The cardboard ensures the equal distribution of shared materials in co-design, implying that the four residents are engaged in a collaborative medium of equal footing. Additionally, as shown in Figure 5, the board's large size allows the residents to work side by side, enabling them to not only focus on their respective areas but also easily transition to others for collaboration. During the workshop, it provides a dynamic and engaging environment for configuring smart home automation solutions.

3.2 Workshop Design

This workshop was designed to facilitate a co-creation process of home automation ideation for cohabitants. Therefore, participants gradually learned how to create a TAP-style automation rule using the cards and were encouraged to craft their own home automation schemes according to their needs. Sharing and learning were encouraged in this workshop, allowing participants to showcase their own schemes and draw fresh inspiration from others' schemes. Furthermore, the workshop promoted collaboration and negotiation among cohabitants in order to gain more insight into the decision patterns in home automation within shared spaces. A total of five workshops were conducted, including two for individuals focusing on designers and smart home practitioners, and three for shared space encompassing six pairs of cohabitants in shared spaces. Whilst this study focuses on the usage of home automation in shared space, the workshops with individuals are considered important as the constructivism from the identity of designers and practitioners is potentially reflected in their actions and discourses during the workshop, which helps us rethink the empowerment of home automation critically. However, in order to avoid a top-down design hegemony, there is no explicitly framed section specifically summarizing the insights from the so-called "designers" and "practitioners". Instead, We see them as a complex of their expertise and experience who are knowledgeable about smart home technologies and beneficiaries of home automation in shared spaces. In addition, the three workshops for shared space cover three types of cohabitant relations including family cohabitants, roommates, and older spouses.

Each workshop involved four participants and was facilitated and documented by four workshop assistants. The workshop lasted for 1-1.5 hours each and took place in the aforementioned living lab. Figure 6 shows the workshop on-site situation.

3.2.1 Process. The entire workshop process was structured into six sections: introduction, tutorial, formulation and sharing, iteration, focus group, and individual interview, where the last three stages had slight variations in specific content between workshops for individual and shared spaces while the first three stages remained identical.

- *Introduction.* Introducing the workshop's theme to participants, explaining how to use the card-based tools, and allowing participants some time to familiarize themselves with the card contents.
- *Tutorial.* Presenting a simple task by workshop assistants and asking participants to make schemes with cards and stickers, such as "Turn on the robot vacuum cleaner and air purifier at 9:00 AM or when you are 50 meters away from home," to ensure that each participant correctly understood the rules for using the card tools.
- *Formulation and sharing*. Asking each participant to independently contemplate their desired whole-house automation scheme and create these schemes through cards and stickers, with sticky notes summarizing the themes. For efficiency during the workshop, after completing a scheme, participants were required to take photos and upload their schemes to an online group chat established for the workshop. Workshop assistants organized these into slide presentations. In the sharing stage, the habitants could view each other's schemes and took turns presenting their own scheme content and explaining their design rationale.
- *Iteration.* In the workshops for individuals, participants were asked to iterate on their schemes based on others' sharing and their own new ideas, explaining their iteration process. In the workshop for shared space, two groups of cohabitants

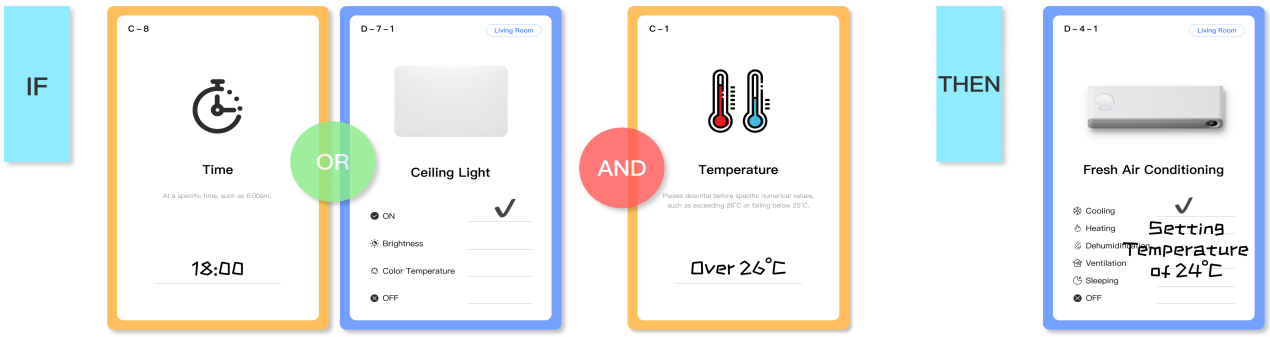

Figure 4: An Example of Automation Scheme Built with Cards and Stickers

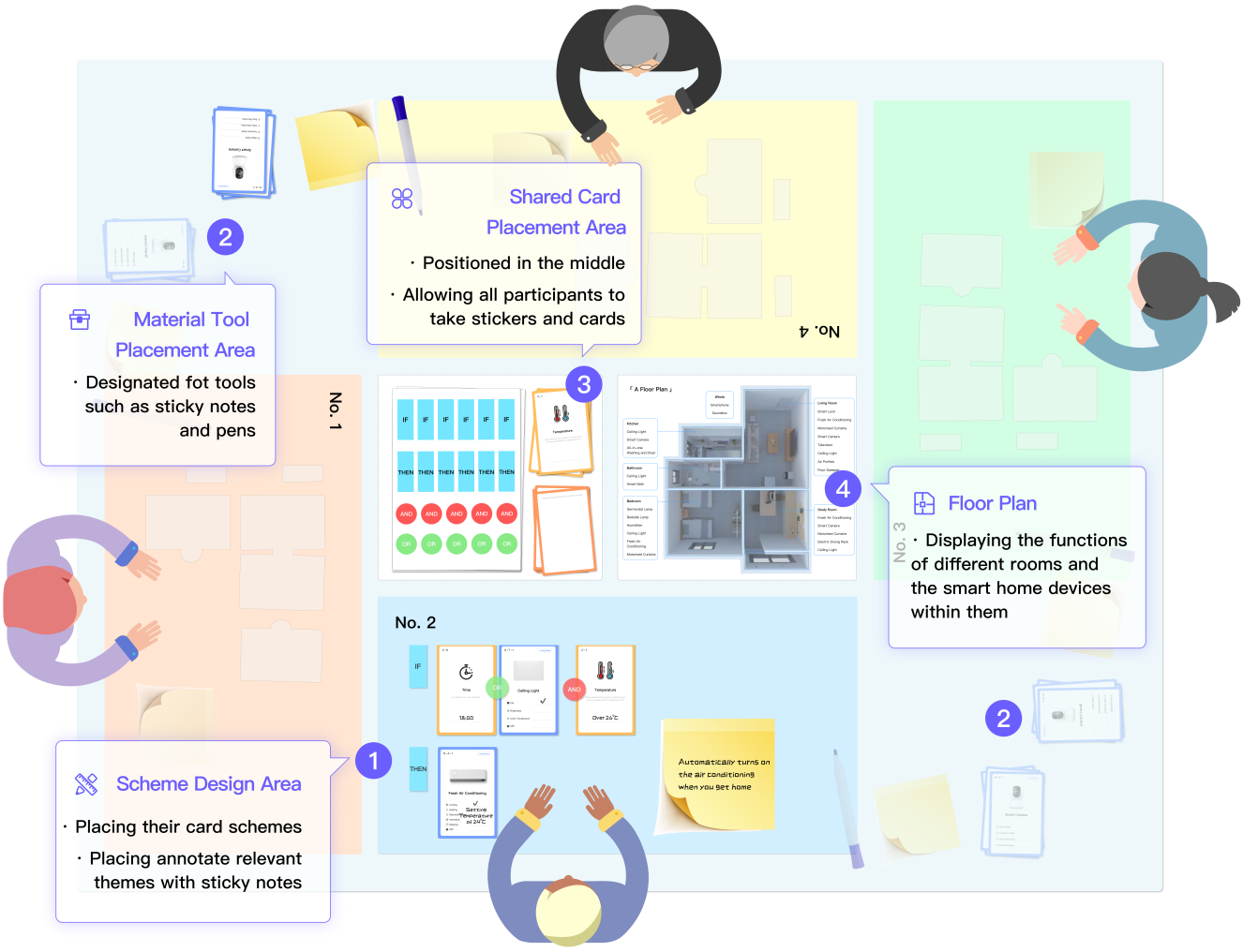

Figure 5: Functional Partitions and Usage of Cardboard

Figure 6: Workshop Photographs: (a) Familiarising the Cards; (b) Constructing Schemes; (3) A Scheme One Participant Designed

discussed their respective schemes and eventually decided on joint whole-house automation schemes.

- *Focus group.* It aims to investigate participants' shared experiences and feelings within co-design. In the workshops for individuals, the questions focused more on how card-based tools enabled the co-design in home automation ideation, while in the workshop for shared space, the focus group was used for partners to present their final schemes, in order to understand conflicts, coordination, or compromises that occurred between cohabitants during scheme iterations.
- *Individual interview.* Considering the constructive risk of inhibiting independent viewpoints when facing multiple participants in the focus group, especially involving interpersonal relationships among cohabitants, semi-structured in-depth interviews were conducted individually for each participant at the end of the workshops. The interviews primarily covered the following aspects: participants' backgrounds (including their technical proficiency, and experience using home automation), problems encountered in using home automation in daily life, experiences using the card-based tools to construct automation schemes, differences from prior experiences, and feelings about interactions with other participants. In the workshops for shared space, additional questions were asked about previous experiences with home automation within the household and specific details related to collaborations, negotiation, compromise, coordination, and even conflicts in joint iterations of schemes.

Four researchers were involved in conducting the workshops as workshop assistants, with one of them responsible for leading the workshop process, managing time, and pushing the activity forward, while the others were responsible for liaising with habitants, guiding them to become familiar with the living lab environment, creating a comfortable atmosphere, observing and recording throughout the entire process. Additionally, they engaged in casual conversations before the workshop started to understand participants' basic situations and make targeted observations during the workshop.

To ensure the feasibility of the processes and identify potential issues promptly, a pilot study was conducted one week before the official workshops. Four qualified and experienced experts in smart home technologies and interactive design, consisting of two living alone and two cohabitants, simulated the entire workshop process in a laboratory environment. The experts affirmed our idea of conducting the workshops in the living lab environment, as it allowed for better rapport-building with the residents and kept their focus on reflecting on their own lives. Meanwhile, the experts suggested modifications to Section 2, changing it from initially giving more open-ended scheme tasks to providing specific ones.

3.3 Make it Happen in Living Lab

The co-design workshops were conducted within a living lab [74] equipped with smart home devices (as shown in Figure 2). Living labs, as recognized as an approach fostering "open innovation" [56], often refer to experimental platforms for everyday context creation through" the creation of a home where the technology or product is available and where users come to stay for a certain period" [2, 53]. In developing our participatory process related to domestic scenes and interpersonal interactions, we sought to leverage the potential of the living lab to explicitly and implicitly facilitate experience-centered design activities. On the one hand, the living established a typical home context to reveal implicit knowledge and potential needs within residents' experience. Various smart home devices are deployed in different functional rooms, aligning with those featured in the card-based tools. It creates a real-life domestic scene that is distinct from conventional lab environments or workplaces for co-design activities, which potentially evokes people's experiences of everyday interactions with smart devices and home automation. For example, the participants engaged in a room tour and device trials before the workshop, allowing them to freely use devices and household facilities as they would at home, as well as chat with workshop assistants about feelings coming from their thoughts. This supports a sensitization process [59] encouraging and motivating participants to reflect on their personal experiences at home before the workshop started, which also facilitated a quicker immersion into the workshop. As such, the living lab acted as a gateway for researchers to access a "hidden world of user experience" [59] and foster meaningful creation [24] during workshops.

On the other hand, the living lab provided an informative responsive space of communication for participants and researchers

throughout the workshop, which significantly supported the rapport establishment and story exchanging. During the room tour, participants easily resonated or empathized with the configurations of certain devices, expressed through spontaneous and vivid comments connecting with their own experiences about dealing with automated devices. Sometimes the conversations were developed by the cohabitants coming together, which led to the sharing of their anecdotes and lifestyles. In this process, heterogeneous attitudes and experiences of different residents towards automation technology are revealed in their various discourses. Much like how some experience-centered approaches [70]capture participants' reactions and concerns, this domestic space shaped the way participants convey their thoughts and values with more modalities during the workshops, such as using examples of devices seen in the room in their expressions to help others understand their past experiences or current needs.

3.4 Participants

A total of 20 participants took part in the workshops. To recruit participants who lived together and had an interest in or experience with home automation, a preliminary screening was conducted using interest forms among those who signed up for the workshops. Additionally, specifically for recruiting people living together, a snowball sampling method was employed which guided us to the cohabitants and families. People who are interested in the activity could share the interest form with their cohabitants and invite them to join. Most of the referees also completed the interest form for registration, while another invited 3 retired residents who had eventually joined the workshop and were orally registered with us. The habitants displayed a wide range of diversity in terms of age, occupations, technical proficiency, experience using smart homes, social roles within their household, and living conditions. It is noteworthy that, to mitigate the common occurrence of clustering among technology enthusiasts through such recruitment methods, we meticulously screened participants to strive for a more balanced representation, particularly from a social-technological perspective across the aforementioned dimensions, which is presented in Table 3, which provides valuable insights into the research findings. Participants' names were anonymized. There were 11 male and 9 female participants, with ages ranging from 20 to 66. Eight participants had backgrounds in design or were practitioners in smart homes and were included in two workshops for individuals as they lived alone. The remaining twelve participants included six pairs of cohabitants and were separated into three workshops for shared space. Their living conditions varied with types of married couples, unmarried couples, three-generation households, and friends living together. The five workshops were successfully conducted over the course of five working days within one week.

3.5 Data Collection and Analysis

The qualitative data covered in the study include demographic data from the recruitment questionnaire, video and audio recordings of each workshop, audio recordings from focus group interviews and individual interviews, and the card schemes created and uploaded by participants during the workshop. The researchers also observed and recorded observational notes during the workshops. All participants signed informed consent forms before the experiment. Data analysis was guided by the thematic analysis approach proposed by Braun and Clarke [9] and involved a two-cycle coding [51] with cross-discussion and evaluation of generated codes and themes among four researchers. Our analysis focuses on the heterogeneous habitants' attitudes towards home automation, the breaking of barriers to empowering residents in home automation systems through the card-based tool, and the impact on power dynamics in collaborative ideation. Specifically, the workshops for individuals leaned towards phenomenological insight provided by the interpretationist nature of participants' highly relevant background to home automation, while the workshops for shared space focused more on the constructivist influence of social factors such as social roles in negotiation among members.

4 FINDINGS

4.1 Different Roles and Obstacles in Experience

The workshop provided an opportunity to gather a group of home automation users to investigate how their heterogeneous characteristics, such as age, occupation, technical proficiency, living conditions, and previous experience with home automation are associated with their performance in co-design.

The habitants revealed their experience in use and attitudes to home automation during the pre-workshop chatting with workshop assistants and individual interviews, which found that almost all of them agreed that those who are more technically competent usually take charge of configuration stuff at home. For example, P13 who was an undergraduate majoring in computer science mentioned that he was in charge of configuring his parents' or grandparents' home automation together with his brother, although he didn't always live in their house. He concluded the phenomenon as *"generally those with these technical skills or backgrounds actually take the lead"* (P13, individual interview). In the shared space groups, P12 who was self-identified as a *"passenger user"* (P12, individual interview) also stated that the access to the devices she could control was provided by her boyfriend P11 who was a smart home enthusiast *"in terms of configuring it all"* (P12, individual interview).

Despite their strong technical background and keen interests in smart home technologies, the residents appeared more willing to share the obstacles they encountered in their previous experiences, some of which were even frustrating. For example, P11 mentioned the burden of debugging during usage and had considered abandoning it because:*"After all, I think I'm kind of the type with a logical or with better understanding. I sometimes come across it and I don't even set it up because it's too cumbersome, and that's one of the things that sometimes causes me not to use it."* (P11, individual interview) Similar experiences were shared by P9, who expressed frustration due to repeated attempts at troubleshooting:*" . . . debug it by myself over and over again, which feels stupid."* (P9, individual interview)

However, for the older people, the high learning cost of smart homes appeared to be the biggest challenge for them not to try automated features. Although the two groups of older adults in the last workshop for shared space were very interested in the various smart home devices in the house as soon as they entered the environment of the living lab and offered to visit, they mentioned in the individual interviews that *"I think these things are worth*

Table 3: Participants Demographic Information

Workshop Session	User ID	Age	Gender	Occupation	Familiarity with Smart Homes	Cohabitant & Relationship
W1	P1	22	Female	Designer	Intermediate	-
	P2	27	Female	Data engineer	Intermediate	-
	P3	20	Female	Designer	Fundamental Awareness	-
	P4	23	Female	Designer	Fundamental Awareness	-
W2	P5	27	Male	Consultant	Advanced	-
	P6	32	Male	Entrepreneurs	Advanced	-
	P7	22	Male	Student	Fundamental Awareness	-
	P8	25	Female	Designer	Novice	-
W3	P9	20	Male	Student	Intermediate	Mother & Son
	P10	45	Female	Homemaker	Intermediate	
	P11	23	Male	Game operator	Advanced	Couple
	P12	24	Female	Designer	Intermediate	
W4	P13	23	Male	IT Engineer	Advanced	Roommate
	P14	23	Male	IT Engineer	Fundamental Awareness	
	P15	22	Male	Designer	Intermediate	Roommate
	P16	21	Male	Designer	Intermediate	
W5	P17	64	Male	Retiree	Fundamental Awareness	Spouse
	P18	65	Female	Retiree	Fundamental Awareness	
	P19	65	Male	Retiree	Fundamental Awareness	Spouse
	P20	66	Female	Retiree	Fundamental Awareness	

using, but I am afraid that I will encounter any problems with the simple operation and then I will have to solve them." (P18, individual interviews). As a group not often involved in the practical ideation, they expressed concern about the barrier to learning:*"Although I have learned it very hard, it is relatively difficult to keep up with this fast-paced information technology."* (P19, pre-workshop)

4.2 Enhancing Perceptibility for Understanding and Enjoyment

Setting up a home automation system can often be a convoluted and uninspiring process, particularly for beginners. However, during our workshop, we discovered that by employing cards as an alternative metaphor — a medium familiar and tangible to many — this intricate process could be made notably more perceptible, alleviating the challenges associated with understanding the various rules and devices involved. The visual clarity of the elements presented on the cards was especially well-received by participants, who remarked,*"I could quickly understand what these devices can do with just one look, instead of going through them one by one."* (P5, focus group) P6 also noted the color and graphics *"not only helped decision-making but also inspired my next steps."* (P6, focus group) Additional feedback included statements like,*"Even when looking at other people's cards, I could easily understand the rules… like an open manual,"* (P13, individual interview) and *"Compared to my previous experiences configuring smart home automation using mobile apps, this method provides me with a better sense of control."* (P5, individual interview)

Likewise, several habitants expressed that utilizing card-based tools for designing yielded a gratifying experience. Following the workshop, P18 conveyed a newfound sense of accomplishment. She shared reflections such as, *"While making home automation setups using cards, I found myself envisioning an improved quality of life."* (P18, individual interview) Others likened the experience to crafting a work of art, commenting *"There's a profound sense of contentment upon completing an automation that truly resonates."* (P10, individual interview) Notably, two residents who shared a common space expressed a desire for us to further develop the card tool by incorporating a set of game-like rules. This indicates a potential avenue for enhancing the engagement and enjoyment of the design process. Additionally, the tool not only simplifies the process of home automation but also fosters social interaction and collaboration among cohabitants. An older group of households noted that the card tool effectively served as a conduit for their interpersonal communication.

4.3 When Participation is Promoted

The co-design process witnessed a significant transformation facilitated by the card tool's ability to help participants articulate solutions from others and critically assess existing ones. People uniformly acknowledged the effectiveness of cards for conveying their automation rules as they engaged with the tool. Similarly, when the habitants were prompted to interpret each other's cards, they also attested to the ease of comprehending fellow participants' automation rules, and even deducing underlying rationales behind these rules.

Moreover, the card-based approach assumed a profound role in fostering inspiration and encouraging reflective practices among participants. Many reported that collisions between their automation rules and those of others sparked novel ideas. This effect was particularly pronounced when people employed diverse devices or methods to achieve specific outcomes. In such cases, these interactions frequently triggered fresh perspectives among partners on

how to deploy similar rules within their own settings. A compelling illustration emerged from a shared-space group wherein P12, influenced by another group's rules concerning kitchen cleaning, extended their insights to their own kitchen automation. Equally noteworthy was the revelation that some people began scrutinizing their automation rules and contemplating their decisions regarding future acquisitions of smart home devices.

As multiple participants converged on the same theme, a tendency to seek triggers that may not have been precisely captured in the scenarios emerged. A pertinent case materialized during a workshop focused on provocative ideas around smart locks. An enlightening instance arose when a participant mentioned the potential issue of fingerprints being left on a smart lock during the Sharing process, this insight prompted P14 to take action with cards on security issues, and then shared his concern with his roommate P13. They built a conversation during the Iteration process, which ranged from the consideration of privacy, and available functionality, to their own daily habits about entering and leaving their homes, interwoven with a discussion of an ideal way to the automated scheme with the smart lock involved in. To mitigate the risk of fingerprint traces revealing the door code, they conceived a deterrent system integrating a smart camera with the door lock together and wrote it down on a custom card. After that, they complete an automation scheme for the security of the door, that is when someone approaches the lock, this system will activate the camera, illuminating its light and signalling recording initiation. They presented this product of their shared decision-making to researchers in focus groups and emphasized that this approach not only deters potential intruders visually but also records any attempts to decipher the door code, thereby bolstering the smart lock's security.

4.4 Unfolding Negotiations for Shared Space Ideations

Negotiations were a common occurrence when the residents were given the space to generate common schemes alongside their cohabitants for their practical life according to their individual card-represented schemes. These dialogues — on various content and between different cohabitants — are subtly uncovered through the trace of iterations with cards. Whilst conveying individual needs on automation in a shared space could be challenging for non-experts, most participants noted that lining up cards on the board helped them express their thoughts, and made the understanding between cohabitants' desired configurations efficiently and easily. The use of cards further unified users with varying digital proficiencies in co-designing smart home experiences, mitigating common contestability issues in such scenarios and serving as a probe in revealing underlying power dynamics. This was especially evident in the 'pilot-passenger' relationships [34] observed, where passenger users reluctantly adopt smart technologies introduced by more proactive 'pilot' users. A case in point is P12, who, despite initial passivity towards her partner P11's enthusiasm for technology, became more involved in the workshop, contributing ideas and actively participating in the development of automation routines. As the digital proficiency gap narrowed, P11 further explored and customized smart devices to align with personal preferences. In the focus group interview, she showed workshop assistants their card-represented schemes and lively demonstrated the discrepant ventilation preference between her and her boyfriend: *"He likes to open windows for ventilation, even in winter. That (the card-represented schemes) means he wants all the windows opened when everyone leaves."* Her concern was also voiced: *"Then it gets very cold when you come back."* Although her boyfriend, P11, also revealed his habit of being *"afraid of heat and often use air conditioner"*, he ultimately compromised and followed his girlfriend's schemes on the plan. Furthermore, some unclear card placements also triggered further discussions among participants, naturally leading the more capable one to help the others debug the schemes. It is showcased by comments from P19 on his 65-year-old wife (P20)'s scheme: *"Sometimes it is a bit messy."* (P19, individual interview) A *"simpler and clearer"* (P20, individual interview) representation of her schemes was then provided by his husband after asking her permission.

The card-based tool highlights differing collaboration and negotiation patterns among groups influenced by the attributes of shared space lived and familiarity with each other. Specifically, the members in couple or familial relationships appear to be more direct and emotional in scheme negotiations, maintaining high acceptance of being concessive and more assertive ideas from partners. A workshop assistant observed that the proportion of contribution by P18 involved in the final scheme was relatively small compared to her husband's, thus investigating if she conceded to such an arrangement in the individual interview. P18 explained this as a *"synthesis"* (P18, individual interview) within their schemes, and her husband had also *"added some supplements"* (P18, individual interview). She attributed her implicit compromise to her husband's work experience and personality:*" He works for the government, so he is more rigid... Sometimes he thinks I should have not said like that if I say something wrongly."* (P18, individual interview) Indeed, solid interpersonal relationships allow these participants to express their attitudes candidly in discourses, indicating *"I will not allow him to do this (setting),"* (P12, individual interview) or making compromises to partners' ideas such as *"Let her be."* (P19, individual interview)

However, unlike those in couple or familial relationships, and instead, those who are roommates or cohabitants thought highly of pursuing equitable distribution of control, and thus strive to use cards for clearer negotiations and satisfying allocations to shared spaces. For example, two groups of cohabitants (P13 and P14, P15 and P16) both explicitly specified the boundaries between private and shared spaces from the beginning of the iteration section. This was identified as a norm that allowed them to autonomously manage their private spaces *"without being intervened"*. (P13, individual interview), and thus the discussion would be focused on how to *"create a comfortable (public) space together."* (Workshop 4) Moreover, as the card-based tools embodied their need expressions avoiding much semantic ambiguity, differences, and conflicts are confronted directly by partners, which was found to shape the communication in a subtle manner with social presence shown. These were identified strongly in the card records and interviews of P15 and P16 where they showed expectations to build equal control and create mutual comfort. They explicitly stated the schemes should be *"done together by two of us"* (Workshop 6) in the focus group and, interestingly, tried to create new automated actions on custom cards and sticky notes for addressing potential competition and habit

differences in cohabitation. For instance, they designed *"automatic flushing when the toilet seat is opened"* (Sticky notes, workshop 6) to prevent possible issues with toilet cleanliness and *"increasing priority"* for shower water assignment to avoid diversion by other usage.

Furthermore, towards the end of the workshops, several participants highlighted that examining card schemes and discussing them with partners had sparked new insights into others' needs, and prompted self-reflection on their past use of home automation at home. For instance, P12 noted that she was aware of her boyfriend (P11) being *"different in his ideas"* (P12, interview) regarding their mindset of approaching their life, even though they had a long history of living together: *"I tend to be divergent... always assuming it would be nice if something could happen in some way. But he tends to be problem-solving, thinking about how to make it happen."* (P12, interview) Self-reflections on previous contributions and concerns to their households are also demonstrated in the individual interview with P9. As a person who is mainly in charge of smart devices at home, he realized that he might need to *"be more family-oriented… consider what family really need"* in home automation.

5 DISCUSSION

In this paper, we reported a co-creation activity with cohabitants through card-based tools and workshops as a means to provide a perceptible and participatory alternative to home automation, which showcased new directions for understanding empowerment in home automation. Meanwhile, the cards served as a "power probe" to provide openness when delving into the challenges of empowerment within collaboration, negotiation and the long-term use of automated technology, which offered pragmatic insights that can be developed into effective design principles. Our findings underscored a critical perspective of viewing home automation as a co-design process that involves diverse stakeholders for achieving appropriate control decision outcomes. This novel paradigm showed that whilst home automation is generally taken as a powerful solution that shapes people's domestic environment and helps them to take control of their lives (which indicates its so-called empowerment), its problematic nature becomes evident when reevaluated through the lens of co-design. In our discussion, firstly we emphasized the significance and value of rethinking home automation and its problems through the lens of co-design. We identified the common design paradigm of home automation as a sort of "problematic co-design" which marginalises some cohabitants in co-creation processes. We argue that automation system designers often neglect the paradoxical notions of empowerment and the "co-design" features of home automation. Secondly, we associated shared materials and processes in workshops with obstacles and sources of empowerment in co-design defined by Zamenopoulos et al. [75], in order to examine what the existing challenges and opportunities of empowerment in home automation systems design are, especially when considering the configuration and long-term use as a co-design process between cohabitants. Finally, we reconsider the implications of empowerment in home automation, providing new insights into the capacities the residents should gain in such empowerment and the principles that designers and researchers need to follow in the landscapes of design research [52].

5.1 Identifying Home Automation as Problematic Co-design for Empowerment

Firstly, our findings suggest that by considering home automation ideation as co-creation by cohabitants, some inherent concepts related to empowerment by traditional home automation could be challenged, avoiding excessive involvement and enactment of domestic power dynamics from the designers. Home automation is seen in HCI domains as aligned with the understanding of ubiquitous computing, aiming at liberating users' efficiency and productivity [7]. However, since the researchers and designers are often considered responsible for designing automated systems as their ends rather than treating them as a means of framing a promising controlled life, this inevitably implies the nature of a top-down approach to empowerment. The results of this were also embodied by many of our participants in their experience of using home automation, which resulted in frustration and system abandonment. Notably, we consider this failure in empowerment as rooted in an oxymoron around "empowerment with home automation", where the interventionism from designers for more autonomous home control conflicts with the expectation that people take power on their own. This parallels Cristiano Storni's critique of "empowerment-in-use" [61] as highlights the incompatibility arising from the role played by design during guiding power balance.

Our findings reveal the inconsistency of power distribution in the control and maintenance of home automatons due to different technical capabilities and social attributes among the cohabitants, which appears to show the demand of capacity to mediate small politics within households. However, taking this issue from a co-design perspective, the problem ultimately attributed to the limitation of a designer-led solutionist commitment in dealing with power issues. Stated differently, home automation designed by a top-down approach may exclude flexibility towards making spaces for all and fostering dialogue between people. This is different from the observation in the workshop when a bottom-up initiative was provided, that fellow residents were able to become co-designers, engaging in the collective ideation of schemes through a collaborative approach. Our participants' responses demonstrated that the co-design process helped bridge differences and resolve obstacles through mutual learning and help among families and roommates. While the motivation might be given by the one-off activity rather than actual technical implementation, this reflects the importance of the scaffolding role that home automation might play. The problems with a top-down domestic design could also be revealed in Berger et al.'s [5] viewpoint that techno-solutionism embedded in the underlying assumptions of designers results in "accidentally evil" issues in the smart home. Our study provides an example of a position shift to home automation designers, from being providers of solutions for domestic technology appropriation to becoming "facilitators" who consider how to build a long-term co-design schema for facilitating participation and collaborations in the usage of home automation. Thus, we call for considering how automation systems can be designed as a participatory platform to support need negotiation in

shared space, leveraging the relationship within families to address issues in the ideation and maintenance of home automation.

5.2 Uncovering Obstacles and Sources of Empowerment from Home Automation System

So far, we have emphasized the significance and value of rethinking home automation, as well as its problems, through the lens of co-design. However, as mentioned earlier, we pointed out some related work in HCI (such as [27, 29, 31, 34]) that underscore the limitations of home automation systems in use which are also shown in our findings. They are usually accepted and categorized by HCI researchers as topics about the contextual appropriation of information technology, which thus emphasizes the additional exploration of social impacts. However, we take a different perspective on this topic, that we view the design paradigm of home automation systems as a matter that needs to be criticized for its deficiency in facilitating the contestability of cohabitants. To do this we associate these systematic limitations in multi-user use with obstacles and sources of empowerment in shared materials and processes of co-design defined by Zamenopoulos et al. [75]. We uncovered three specific aspects that raise awareness for researchers and designers to consider, which include 1) the perceptibility of TAP rules and information as critical resources, 2) the limited participation exacerbating barriers, and 3) diverse modalities for expression.

Firstly, by identifying traditional TAP and their user interfaces as critical resources in the co-designs of home automation, our finding shows the inadequate perceptibility of related rules and information poses a barrier for non-technical groups in discourses related to power dynamics in shared spaces. Specifically, some older habitants have mentioned the obstacles and frustration in dealing with information in home automation systems from their experience, which underscores the negativity of unavailable critical resources owing to varying abilities. When people are hindered from establishing automated rules across devices and conditions in accordance with their needs, one of the conditions of empowerment appears to be unmet, which is reflected in the emphasis of Zamenopoulos et al. [75] that co-designers should be able to control and access the key resources in a co-design process as "power comes with the mobilization and control of critical resources". The discourse of viewing domestic technology as a resource has also been mentioned by Taylor et al. [66]. Related to this, previous research has also pointed out the occurrences of problematic critical resources being over-informative [42] or being concealed [34]. It poses potential challenges for the family members in different capacities to control and access critical resources at the same level. However, in our workshops, the card-based tool served as a visual metaphor for traditional TAP. It is perceived as more relatable and perceptible to acquire information and materials about devices and conditions to create schemes, thus supporting decision-making around their life choices. Also, participants' enthusiasm for negotiation in ideation demonstrated how more perceptible resources supported contestability. It is also remarkable that access to key resources is also facilitated through assistance from other cohabitants, as proficiency in using the cards is enhanced with the help of others.

Furthermore, the ignorance of collaboration and negotiation during the use of home automation systems exacerbates barriers arising from the divergent values and interests of residents in shared spaces, which disables vulnerable users in power from making impacts on the co-design. Zamenopoulos et al. [75] identified the boundaries between different social worlds as obstacles to empowerment. This is embodied in our findings and also existing work [19] where different users with different social roles show different expectations on prioritizing and approaching the use of automation variously. However, as current home automation systems rarely focus on the concept of co-creation, they struggle to handle the conflicts from multi-source demand and ultimately, create problems when inherent power dynamics impact the decision of final schemes. Parallel to the key source for addressing this obstacle noted in Zamenopoulos et al.'s work [75], in our study, the workshop is designed to "facilitate the formation of non-hierarchical rules of participation". The process, from individual ideation to collaborative iteration sequentially, ensures the allocation of equal time, resources, and personal space to every resident within the social group. As such, it could maintain the openness of home automation ideation to different stakeholders as beneficiaries and provide spaces for constructing the solutions together. Notably, the pursuit of equal participation is not contradictory to the advocacy mentioned in some studies [23, 73] of creating individual accounts for users to separate the participation. We acknowledge the benefits of individual accounts in managing diverse needs. However, even if systems are designed as compartmentalized, attention still needs to be paid to issues of participation power among different users when individuals' actions affect collective resources.

Moreover, as a tangible tool connoting multi-modal information, the card-based tool shows flexibility for diverse expression. It enhances individuals' ability to make meaningful conveyances to the matter they care about, and in turn, motivates them to increase their desire during co-design with partners. However, whilst mobile-based user interfaces are widely used as efficiency as well as precision are considered priorities for commercial home automation systems, it is still significant to create diverse modes of expression. As stated by Zamenopoulos et al. [75], the difficulties in connecting diverse ultimate knowing are defined as one of the key obstacles to empowerment in co-design. It is not surprising in home automation practices that cohabitants have different ways of expressing or knowledge due to different technical capacities and social roles. This somehow mirrors the diversity of participants in a co-design process, which indicates home automation should allow various modalities to express ideas and needs in order to make space for uncovering issues in collaboration with their family members. In our workshops, different expressions came from the flexible use of cards, shared materials used for schemes, and dialogues taking place between participants, which contributed to fleshing out the understanding of the needs of cohabitants during negotiations and reflection. Whilst the need that 'helps habitants identify further opportunities for meaningful additions' has also been emphasized in home automation research [42], However, there are still challenges remaining in turning into practices, such as which modalities of data should be considered, how these data construct the self-reflection and scheme generation, and how to balance diversification and consistency required by TAP.

5.3 Facilitating Empowerment in Home Automation

Based on the discussion above, we highlight the implication of "empowerment in home automation" as "granting more contestability to different cohabitants within the collective use of automated domestic technology". Combining this implication with the four types of empowerments in co-design proposed by Zamenopoulos et al. [75], we identify the ideal conditions to achieve this contestability for diverse users as i) People have the self-awareness of identifying problems and needs in daily life and subsequent problem-solving ability; ii) Collaboration can be built for negotiating diverse members' device usage requirement; iii) People can influence final solutions through fostering participation in collective decision-making; iv) People can continuously gain proficiency in mastering smart devices and home automation management. Whilst system usability and accessibility are still vital as key metrics for successful technology appropriation and cannot be left in the basket, it is crucial to consider whether the home automation system is viable as a co-design process to address the "wicked problem" in use.

Furthermore, our findings also highlight two principles related to empowerment in home automation, shedding light on how researchers and designers could empower households through automation systems. Firstly, designers should take on the role of "facilitators" for empowerment while avoiding bringing power imbalance into households through top-down design. Although the majority of information system designers and engineers primarily prioritize the factors related to product commercialization, we argue that the focus on power dynamics does not contradict it. Instead, recognizing the socio-technical nature of this topic to promote technological democratization can lead to greater well-being alongside enhanced economic benefits. Thus, the designers need to expand their horizons in methodology, further considering the following aspects in their designs: i) Reducing the burden on marginalized groups through lowering barriers and increasing inclusivity; ii) Fostering mutual understanding among diverse users through enhancing participation and collaboration iii) Motivating power distribution through encouraging family members' self-reflection on interpersonal relationships and device usage.

Secondly, the ideological diversity embodying inherent power dynamics and social norms in the ideation and use of home automation must be considered. As noted in the findings, cohabitants as roommates revealed distinct communication and negotiation patterns compared with those as families —ranging from a deliberative ideology to an Agonistic model as often mentioned in Social literature [45]. Our workshops also reveal a group of people that are not explicitly impacted by the co-design process, such as some older users who did not gain new insights into partners' habits or make any changes to their communication with each other through provocative sections with cards, and instead, showing strong consistency between its value and action in using devices. This could be attributed to the firmness and complexity of rules and power distribution within households, which have developed over the course of members' long-term life practices. However, whilst people may have already established unique decision-making and collaboration patterns, some of which researchers might view as needing correction, which manifests the interventionist perspective. This provides a new point of contention between maintaining the inherent power dynamics and breaking the hierarchies of households. While we are clear in our emphasis on a more equitable, power-oriented approach in home automation ideation, the question remains in the long-term management and maintenance of smart devices: Is it more appropriate to acknowledge hierarchies, as suggested by some discourses such as[73], and establish a managerial model for home automation that distinguishes between administrators and other users? Alternatively, should we prioritize the pursuit of democratic involvement from various stakeholders, even sometimes coming into Agonistics [69]?

As such, the lesson for designers and researchers is to understand how these deeply ingrained power dynamics influence the use of technology, and how researchers can balance the significance of empowerment with native social norms, avoiding it becoming a one-sided imposition of democracy. It is notable that, in line with the discussion above, we argue designers as "facilitators" of empowerment do not necessarily entail a complete redistribution of domestic power. Instead, as some inherent critiques in design have highlighted, the precondition of fostering empowerment lies in the reflection around who determines their life and whose "preferred situations" are designers to design [30, 58].

At last, we would like to emphasize that empowerment in home automation is not limited to the discourse around home automation technology itself. Whilst this work highlights the divergence among cohabitants within the context of home automation as well as the potential implication of empowerment brought about by the involvement of the card-based tool, the primary contribution is not positioned in the changes in modalities to the specific technological forms. Instead, we dive into the neglect of unresolved power issues behind broader domestic technologies and offer an alternative framing by trying to integrate co-design principles and knowledge into these practices. Taking previous studies around smart homes and domestic technologies into account, the issues of the lack of contestability exist widely in multi-occupancy environments because of the differential technological capabilities, and physiological and social characteristics of residents. This often results in a dominant-subordinate socio-technical pattern or the marginalization of certain populations from technology usage [34, 73]. As such, and as previously noted, we call for more researchers and designers to incorporate co-design advocacy into broader considerations of family technology design.

6 LIMITATIONS AND FUTURE WORK

In our study, we focused on the empowering challenges faced by heterogeneous households in home automation. While our workshops included a wide range of members of a household in terms of demographics, social roles, and technical proficiency that supported the breadth of the insights, there were still limitations regarding participant selection. Finding individuals with the necessary experience of living in shared spaces and using home automation who were also interested in participating in the research proved to be practically challenging. Furthermore, the high organizational costs associated with workshops resulted in a limited number of participants, with each workshop accommodating only four participants involving two pairs of cohabitants. Obviously, in situations involving more

than two people in a residence, such as multi-generational families, these power dynamics and social factors would become even more complex. We hoped that more "design in the wild" methods would be adopted to explore the intricate interpersonal relationships and usage patterns in more complex shared space environments in the future.

Additionally, while our card tool was based on existing commercial automation user interfaces, our intention was not to propose a standardized card toolkit for this topic. We recognized that design always unintentionally represented certain choices, which might introduce some functional alienation or simplification to TAP. While we believed these issues were worth further discussion, we also emphasized that we viewed this research as a starting point for discussions surrounding the implications of home automation and co-design. Also, we recognized that our current activity may not fully capture all the affairs and processes related to the infrastructures and supplementary technology of home automation. However, we believe that the perspective on empowerment we highlighted — to be contestable among cohabitants — also holds relevance for engaging in a broad discussion surrounding home automation. We expect future studies to include these affairs and offer practical improvement specifically.

Furthermore, more cultural factors behind home automation usage need to be considered seriously. Participants in this study are situated in East Asian cultural backgrounds, potentially aligning with the power dynamics and social interaction patterns in East Asia. While we acknowledge that introducing more on the cultural context from a socio-cultural perspective would provide clarity and value to discussions about family social and power relations, it might deflect the central focus of this work. Nevertheless, we emphasize the importance of this constructivist epistemology around cultural backgrounds in examining home automation practices through the co-design lens as cultural differences have profound implications on what obstructs to collaborative use of home automation and how to address them.

Lastly, we anticipated that the concept of co-design could inspire the development of more usable and controllable co-design materials in the future HCI community, to be introduced into real home environments. However, this would require significant technological investment to address interoperability issues in smart home technologies and challenges arising from different service vendors.

7 CONCLUSION

This paper has provided a novel perspective on empowerment in home automation through card-based co-design workshops. The findings from our co-creation initiative underscore the importance of fostering perceptible and participatory experiences. Moreover, the stories revealing the negotiation patterns and social dynamics among diverse cohabitant types such as families and roommates are unveiled during the workshops. Our approach frames current home automation as a "problematic co-design" process, highlighting three design aspects as both obstacles and sources of empowerment. We underscore the capacities that habitants need from empowerment in home automation and thus call upon designers and researchers to consider repositioning themselves and treating power dynamics in shared space critically in the future.

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