Transparent Barriers: Natural Language Access Control Policies for XR-Enhanced Everyday Objects

Kentaro Taninaka
Graduate School of Media and Governance
Keio University
Fujisawa, Japan
taniken@sfc.keio.ac.jp

Rahul Jain
Department of Electrical and Computer Engineering
Purdue University
West Lafayette, Indiana, USA
jain348@purdue.edu

Jingyu Shi
Elmore Family School of Electrical and Computer Engineering
Purdue University
West Lafayette, Indiana, USA
shi537@purdue.edu

Kazunori Takashio
Faculty of Environment and Information Studies
Keio University
Fujisawa-shi, Japan
kazu@sfc.keio.ac.jp

Karthik Ramani
School of Mechanical Engineering
Purdue University
West Lafayette, Indiana, USA
ramani@purdue.edu

Abstract

Extended Reality (XR)-enabled headsets that overlay digital content onto the physical world, are gradually finding their way into our daily life. This integration raises significant concerns about privacy and access control, especially in shared spaces where XR applications interact with everyday objects. Such issues remain subtle in the absence of widespread applications of XR and studies in shared spaces are required for a smooth progress. This study evaluated a prototype system facilitating natural language policy creation for flexible, context-aware access control of personal objects. We assessed its usability, focusing on balancing precision and user effort in creating access control policies. Qualitative interviews and task-based interactions provided insights into users' preferences and behaviors, informing future design directions. Findings revealed diverse user needs for controlling access to personal items in various situations, emphasizing the need for flexible, user-friendly access control in XR-enhanced shared spaces that respects boundaries and considers social contexts.

CCS Concepts

• **Security and privacy** → *Usability in security and privacy.*

Keywords

Access control, Natural language policies, Extended reality, Mixed reality, Everyday objects, Tangible user interface

CHI '25, Yokohama, Japan

ACM ISBN 979-8-4007-1394-1/25/04
https://doi.org/10.1145/3706598.3713656

ACM Reference Format:
Kentaro Taninaka, Rahul Jain, Jingyu Shi, Kazunori Takashio, and Karthik Ramani. 2025. Transparent Barriers: Natural Language Access Control Policies for XR-Enhanced Everyday Objects. In *CHI Conference on Human Factors in Computing Systems (CHI '25), April 26–May 01, 2025, Yokohama, Japan.* ACM, New York, NY, USA, 20 pages. https://doi.org/10.1145/3706598.3713656

1 Introduction

Extended Reality (XR) technologies have made significant strides in recent years, with numerous companies developing advanced Head-Mounted Displays (HMDs). Recent promotional videos [1] [2] by leading companies demonstrate an increasing interest in integrating HMDs into daily life. One promising approach involves developing XR applications that utilize everyday objects. These applications include overlay of useful information or advertisements on everyday objects [37, 59, 89, 99], providing interfaces for device operation [13, 38, 43], or employing the objects themselves as Tangible User Interfaces (TUI) [19, 28, 30, 31, 33, 42, 47]. The implementation of such XR applications is becoming increasingly accessible due to the emergence of authoring systems designed to simplify the process [39, 62, 96].

When XR applications target daily life scenarios, it naturally follows that their scope must encompass not only private spaces but also shared environments. This inherent inclusion of shared spaces introduces a significant challenge: the consideration of the access policies of everyday objects, spaces, and buildings when outputting virtual content becomes very critical for smooth sharing. In private spaces, most objects belong to a single user, presenting few issues when interacting with them through XR applications. However, in shared spaces where multiple individuals place and interact with various personal belongings, the situation becomes more complex. Without proper consideration, an XR application might inadvertently place virtual objects on someone's personal belongings, drawing unwanted attention through prolonged focus caused by overlays such as advertisements or annotations [72]. Additionally, integrating virtual interfaces on these objects may prompt interactions that deviate from their intended use, thereby infringing on ownership as described by Belk [14]. Such scenarios may cause discomfort and intrusion for object owners, as the system could encroach on their belongings. Similarly, application users may experience a loss of trust in the system if it appears to promote actions that inadvertently infringe upon the ownership rights of others. These issues underscore the need for deliberate approaches to managing virtual content in XR applications, particularly within shared environments.

Many XR systems remain at a prototypical stage of development, where virtual objects are automatically attached upon recognizing physical objects. This approach leaves access control to the discretion of the author and limits opportunities for user intervention. Existing research on output control in XR typically focuses on location-based methods or personal workspaces [20, 45, 82]. However, these approaches do not adequately address the control of virtual object outputs in relation to everyday items, spaces, and buildings in shared environments. While concerns have been raised regarding the attachment of virtual objects to items owned by others [1, 55], to the best of our knowledge, no existing research has thoroughly discussed specific approaches or systems addressing this issue with a focus on user comfort and social acceptability in shared environments. Moreover, the ambiguity in everyday objects' access control policies complicates the situation. Implicit policies, such as "the first person to touch an object is the owner" or "do not touch others' belongings," are common [64, 81], but it is exceedingly rare for individuals to formulate and articulate such explicit policies as "This bottle can be used by family members between 10:00 and 18:00." Often, individuals have not even decided on the content of who can access which objects until prompted [49]. Given the emergence of XR applications that attach virtual objects to everyday objects, it is now imperative to consider how to incorporate these ambiguous access control policies into XR applications.

In this study, we aim to address this gap by exploring how individuals perceive and grant permissions for XR applications to interact with their everyday objects. Our research investigated access control for everyday objects in XR environments. We conducted interviews with 13 participants, revealing complex, context-dependent needs for access control. Key factors influencing decisions included relationships, object attributes, time considerations, past experiences, and urgency of use. Based on these insights, we developed a prototype system that enables the creation of natural language policies through user-agent interactions and allows users to input all provided contexts. This system addresses three key requirements: interactive policy creation, granular policy description, and system-level policy comprehension. We evaluated the system with 12 participants across three scenarios: a living room, a workspace, and a cafe lounge. While the system successfully captured complex user requirements, evaluations revealed both its strengths and limitations. Users appreciated the flexibility and granularity of the system but also found it time-consuming and challenging to use in some cases. These mixed reactions underscore the need for systems that cater to varying user preferences.

The key contributions of this research are:

- Comprehensive investigation of access control needs for everyday objects in XR, revealing their complexity and strong context dependence.
- Empirical insights from user evaluations across three scenarios, highlighting trade-offs between user effort and system accuracy in access control decisions for XR applications.
- Design recommendations for future access control systems that balance automation for users seeking simplicity and control for those with strict policy requirements.

2 Related Work

2.1 Access Control in XR

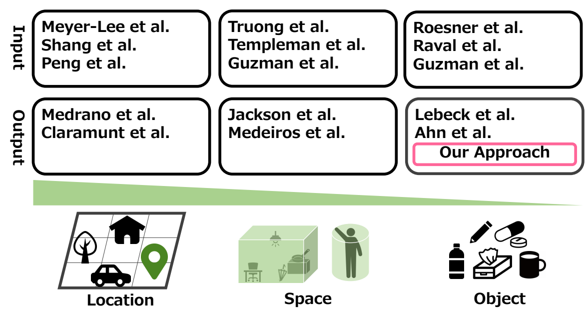

Figure 1: Positioning of This Research. We classified security and privacy concerns in XR along two axes: input and output. From left to right, the scope narrows from location-based information, to spaces such as rooms or personal workspaces, and finally to individual objects. Our approach focuses on the bottom-right quadrant, addressing object-level concerns in terms of output.

Research on security and privacy issues in XR environments has significantly expanded in recent years [27]. A unique aspect of XR applications is their constant detection of the physical world and placement of virtual objects, raising security and privacy concerns. Roesner et al. classified the threats arising from using AR into three main types: input, output, and data access [79]. In our analysis of XR access control, we have categorized it into input and output control, each further refined based on location, space, and object levels (Figure 1).

The progression from location to object level in input access control corresponds to an increase in the granularity of information being managed. At the location level, research focuses on managing the emission of location information or GPS data from devices [61, 69, 86]. Moving to the space level, studies address the management of 3D spatial models or video footage of entire spaces acquired by devices [25, 92, 93]. The most granular level, object-level control, is particularly crucial for XR due to the constant video capture, aiming to exclude footage containing objects with personal information. For instance, Roesner et al.'s World-Driven Access Control, which issues passports for objects to manage input in spaces containing those objects[80]. Raval et al.'s approach allowing users to

[1]Hello Apple Vision Pro https://youtu.be/IY4x85zqoJM?si=_IPn8dMV7-Q-SWy8, accessed on September 9, 2024
[2]This is Meta Quest 3 https://youtu.be/Exu7r2vZpcw?si=-0pbhqI944wyLxb6, accessed on September 9, 2024

set bounding boxes to restrict video capture of specific areas [75, 76], and Guzman et al.'s SafeMR, which manages visual information at the object level by altering abstraction levels[26]. The abundance of research on input control, particularly at the object level, reflects the critical importance of protecting personal information.

On the other hand, output access control in XR, while also adopting location, space, and object-based approaches to manage the placement of virtual objects, has been less extensively researched. According to Guzman et al., there is a lack of literature focusing on managing access control for output in XR environments [36]. At the location level, approaches involve prohibiting the placement of virtual objects within specific coordinate ranges[20, 82], while space-level research focuses on restricting virtual object placement in human workspaces or defined spatial areas [45, 60]. However, research on object-level access control in XR environments, particularly concerning everyday objects, is even more scarce. For instance, Lebeck et al.'s Arya system functions as an operating system to prevent output on critical objects like traffic signs or billboards[56, 57]. On the other hand, diverging from approaches focused on whether virtual objects can be placed on physical objects, Ruth et al. have explored methods for managing access control of virtual objects themselves in multi-user settings [84].

While object-level access control has been addressed in some existing research, the specific domain we aim to explore remains largely untouched. Systems like Arya primarily focus on preventing malicious applications or system bugs from obstructing users' real-world view with virtual objects. However, these systems do not consider scenarios where benign TUI applications might inadvertently attach virtual objects to others' possessions without proper access control checks. Prior related research does not extend to the more nuanced interactions enabled by XR, such as touching, moving, or discarding augmented everyday objects through virtual interfaces[2, 57]. Our research aims to address this gap by investigating how users perceive and grant permissions for these expanded interactions in everyday XR use.

2.2 Access to Everyday Objects

Access refers to the right to use an object with the owner's permission. While sharing is a related concept, access differs in that ownership is not transferred, and the responsibility for maintaining and managing the item does not remain with the owner [11]. The process of forming access has been elucidated through psychological and sociological research, particularly via interviews with young children concerning their understanding of ownership, including everyday objects [71]. By the age of four, children comprehend the normative aspects of ownership, recognizing that the person who initially possessed an item [32, 81] or holds access rights to a particular resource is the owner [67]. Children also understand that they possess more rights over their own belongings than over others' [54, 64] and avoid taking others' property without permission [24]. This behavior is rooted in the anticipation that unauthorized use of someone else's property will cause discomfort to the owner, thus deeming such actions inappropriate [70]. From a young age, children implicitly understand the rule or policy regarding access, encapsulated by the notion that one should not touch others' belongings without permission. Furthermore, discussions on self-identity suggest that people consider their possessions as extensions of their own bodies [10, 14]. This implies that touching someone else's belongings requires similar consent to touching their body, and the conditions or permission for access may vary according to the individual.

Several studies have discussed how individuals grant access to their possessions. Nancekivell et al. conducted interviews with children to understand their perceptions of permissible actions regarding their own and others' possessions [64]. The findings revealed that children recognize permissible actions include non-contact use (e.g., looking at or desiring an item), contact without alteration (e.g., wearing an item), and actions involving no damage or intentional alteration of the item. They also acknowledged permissible behaviors such as sharing with others, gifting, returning the item to its owner, or consulting an adult. These behaviors varied depending on the presence of the owner and the specific context. Conversely, Jenkins et al. interviewed college students and older adults about the conditions under which they would lend items without involving a market [49]. The study indicated that human relationships and roles play a crucial role in lending decisions. Other significant factors included the attributes of the item, such as its price and type, conditions related to time and place, and expectations regarding the item's condition upon return. Both lenders and borrowers emphasized the importance of returning items in good condition.

From these findings, we can infer general principles regarding access control policies for a broad range of possessions, including everyday objects. Individuals are likely to combine various contexts and permissible actions to decide whether to deny or partially grant access in specific situations. However, it is important to note that these interviews covered a wide range of possessions and were not specifically focused on everyday objects. Furthermore, studies on access control prototypes for IoT devices in smart homes have involved interviews to determine which individuals[58, 87], based on their relationship to the user, can access which functions of the devices and the reasons for these permissions[34, 40].

Currently, there is a lack of deeper insights for studies through appropriately positioned interviews addressing the extent to which actions prompted by Mixed Reality (MR) applications are permitted by the owner. Extant research has not adequately addressed the acceptability of MR-specific engagements that deviate from conventional norms, such as prolonged visual fixation via virtual overlays or temporary virtual object manipulation for interface purposes. We are inspired by this need for clarification and appropriate implementations which can help us unravel the policy area for everyday objects.

2.3 Access Control Policy Generation and Management

2.3.1 Manual Policy Management. Access control system utilizing policies can handle diverse contexts, but a significant drawback is the need to generate policies that encompass a wide range of scenarios. Traditional access control systems required these extensive policies to be input in a programming format via PCs. However, efforts have emerged to address this challenge. One notable example of a markup language commonly used in ABAC is XACML, which administrators can use to manage access control with simple code [7]. Additionally, there have been developments to make these markup languages more accessible for everyday use. For instance, Nergaard et al. proposed a system where administrators can generate policies through a visual programming-like interface by combining blocks [68]. Additionally, several interfaces have been suggested that allow users to manage policies using visually intuitive graphical representations [51, 63, 77, 78].

In the context of Mixed Reality (MR), discussions around access control often precede broader issues of security and privacy, leading to usability evaluations of proposed systems. In earlier studies, approaches such as the Vampire Mirror have been relevant, where users could change the viewing permissions of their owned virtual objects [15, 16]. More recent studies have explored methods like Tap Pair and Gaze Pair, which involve changing access rights through human motion [22, 88]. Notably, research by Rajaram et al. focused on interfaces suitable for sharing virtual objects, involving experts to organize how virtual objects should be shared [73]. Their study explored using virtual menus in MR to manage access to virtual objects, gestural controls for sharing decisions, and silent speech commands to maintain privacy.

2.3.2 Automated Policy Management. There is also a discussion on methods for automatically controlling access with minimal human intervention. When integrating models like ABAC that handle extensive contexts, traditional manual policy input is augmented with machine learning techniques to dynamically generate and manage policies. To alleviate the difficulty of accurately inputting and managing policies, there are processes for generating policies from natural language specifications [6, 65, 66]. Systems can also collect access logs from user networks to create policies based on context such as time and location [5, 18, 53]. Furthermore, Policy Administration systems exist to identify and rectify misconfigurations, such as excessive privileges or malicious access, thus alleviating the burden of managing extensive policies [5, 8, 95]. Recently, there have been efforts to use Large Language Models (LLMs) to generate and manage policies from natural language inputs, translating them into machine-readable markup languages [90, 98]. These efforts are expected to enable more flexible and efficient policy management systems.

Managing access control for everyday objects in XR environments presents unique challenges compared to traditional IoT devices. The rapid turnover and context-dependent nature of everyday objects make them particularly difficult to manage. However, this situation presents a trade-off in policy generation and management. Automatic policy generation systems could potentially alleviate the burden of frequent updates, but they may struggle to maintain accuracy without human intervention [48], especially given the short lifecycles and diverse contexts of everyday objects. On the other hand, manual policy creation can ensure higher accuracy but at the cost of significant user effort.

As we move towards implementing access control for everyday objects in HMD-based XR applications, it's crucial to determine what kind of system would be most effective and desirable for users. Our research aims to shed light on this question by using prototype systems to explore user preferences, focusing on the trade-off between security and convenience. We will investigate how users navigate this balance and what features they prioritize in an access control system for everyday objects in XR environments.

3 Survey on Access Control of Everyday Objects

We aim to design an access control model focused on everyday objects. However, there is a scarcity of research discussing access control applied to everyday objects in shared spaces and people's desires concerning it. Therefore, we conducted a survey referencing literature that investigates user access management for smart home IoT devices[40], and two studies that discuss access to possessions, including everyday objects [49, 64]. Our comprehensive survey on access control in MR shared spaces explored how 13 participants (P1-13) manage access to their personal belongings in various shared environments. The survey consisted of two parts: an online survey and a follow-up interview. Participants first completed a 20-30 minute online survey, which was designed to gather data on their attitudes towards object sharing and access control in MR environments. The data on the participants' choices and preferences is summarized in Table 1. Following the survey, each participant engaged in a 15-minute semi-structured interview, allowing for more in-depth exploration of their responses and gathering qualitative insights.

3.1 Survey and Interview Methodology

The survey aimed to investigate participants' attitudes towards access control of everyday objects in shared MR environments. It was structured into four main sections: basic information, object access permissions, contextual factors, and demographic data. The full survey contents are provided in Appendix A. A key focus was placed on understanding the levels of interaction participants would allow with their personal objects, as well as the underlying rationale for their access control decisions.

3.1.1 Interactions Levels. We began by reviewing a variety of studies focused on everyday objects and categorizing the associated behaviors. Subsequently, we referred to the six coding categories from Nancekivell et al.'s study, which examined the types of actions young children allow with their personal belongings [64]. We adopted the categories of use without contact, contact without modification, and modification as they were originally defined. Building on these categories, we integrated the limitations identified by children, focusing on actions that could harm the objects. We also considered Jenkins et al.'s findings on lending, where the potential for damage influences lending decisions [49]. Based on this, we revised the modification category to emphasize whether the process of restoring changes—referred to as re-sacralisation by Jenkins et al.—could be achieved. Additionally, we expanded the sharing-giving category to include discarding, defined as the relinquishment of ownership. This led to the creation of the revised category discarding-giving.

Thus, we defined five levels of interaction (Figure 2):

Use-Without-Contact: This level involved scenarios where MR applications interact with objects without physical contact. Participants considered situations such as AR applications overlaying real-time environmental information on everyday objects [3, 37, 46, 99], language learning tools utilizing real-world contexts [17, 29, 44], and virtual manuals providing interactive guidance

	Gender	Age	Shared Space	Relationship	Objects
P1	Male	26-30	Office	Subordinate, Colleague, Boss	Mug, Pencil Case, Mouse
P2	Male	26-30	Workplace	Colleague	Smartphone
P3	Male	21-25	Company Office	Boss, Colleague	Umbrella, Tissues, Charger, Adapter
P4	Female	26-30	Living Room, Kitchen, Bathroom	Partner	Smartphone
P5	Female	21-25	Laboratory	Colleague	Computer, Writing Utensils
P6	Female	21-25	Laboratory	Colleague	Book, Food
P7	Male	21-25	Station, Laboratory, Office Classroom	Colleague, Stranger, Friend	Tablet Device, Laptop
P8	Male	21-25	Laboratory	Colleague, Friend	Computer, USB Hub, Earphones, Drinks
P9	Male	26-30	Library, Classroom	Colleague	Computer, Mobile Phone, Earphones, Pen, Notebook, Drinks
P10	Male	21-25	Workspace	Colleague, Friend	Drinks, Books
P11	Male	18-20	Laboratory	Colleague	Umbrella, Backpack, Tea Bottle, Headphones, Mobile Battery, HMD
P12	Male	21-25	Office	Colleague	Backpack, Umbrella, Bottle, Mint Candy, Computer, Mouse
P13	Male	21-25	Laboratory	Colleague, Teacher	Charging Cable, Data Cable, Soldering Iron

Table 1: Participant data with shared spaces, relationships, and objects.

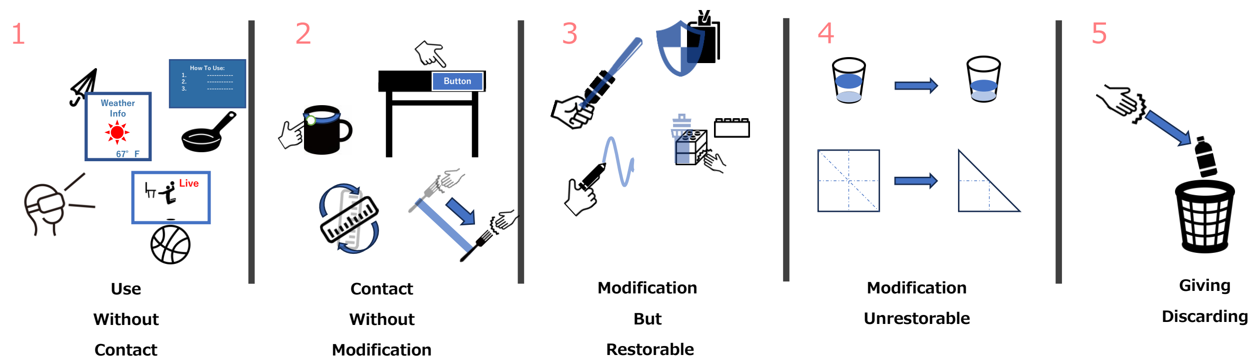

Figure 2: A five levels of action framework for everyday objects, representing a spectrum of increasingly impactful interactions. From left to right, the stages are: 1) Use-Without-Contact, involving non-contact actions such as looking or listening; 2) Contact-Without-Modification, where objects are moved or rotated without altering their form; 3) Modification-But-Restorable, encompassing actions that temporarily change the object's shape, such as denting or bending, but allow for restoration to its original state; 4) Modification-Unrestorable, including actions like cutting or reducing volume that permanently alter the object; and finally, 5) Giving-Discarding, representing actions that relinquish ownership, such as throwing away or gifting the object.

[50]. This level also included examples like enhancing personal memories by overlaying digital information onto physical objects [21].

Contact-Without-Modification: The second level introduced physical interaction without permanent changes to the object. Scenarios presented included everyday objects within an interactive TUI system that uses projected augmented reality. Participants also considered examples of touching objects[4, 38], moving and rotating [19, 31, 33, 91], or tracing their edges to manipulate connected digital systems [39, 52], exploring the boundaries of physical interaction in MR environments .

Modification-Restorable: This level introduced the concept of temporary alterations to objects. Participants evaluated scenarios such as using everyday objects as tangible proxies in XR applications [1, 35, 42, 47, 100], or intentionally denting objects to manipulate connected digital products [9, 83].

Modification-Unrestorable: The fourth level considered permanent changes to objects. Participants reflected on scenarios like cutting everyday objects to create custom user interfaces [12], or extensively modifying items to manipulate IoT devices [23].

Giving and Discarding: This final level represented the most extreme form of access, granting full permission to do anything with the object, including disposal. The primary example provided was the act of throwing the object away in a trash can [85, 94], which explored participants' willingness to relinquish complete control over their possessions in an MR context.

3.1.2 Survey Design. Based on the interaction levels defined earlier, we designed a survey to capture meaningful data regarding access control in MR environments. Participants were presented with realistic scenarios involving everyday objects. These scenarios included various levels of interaction, such as non-contact use (e.g., visual overlays projected onto objects), physical handling without permanent modification, and actions that might lead to alteration or disposal of the object. This contextual framing was intended to prompt participants to reflect on both practical and security-related challenges in shared MR spaces.

Further, participants were made aware of risks specific to XR applications, particularly the possibility of objects being subjected to atypical or unintended use. For instance, objects might display virtual advertisements, prompting prolonged engagement, or be manipulated to serve as interfaces for controlling IoT devices, leading to changes in spatial arrangement. Additionally, objects could be incorporated into AR games, resulting in vigorous or repetitive physical interactions. In extreme cases, objects might be perceived as disposable due to contextual changes in MR environments, leading users to treat them as waste. Participants were prompted to reflect on these risks and specify the extent to which they would permit or restrict such interactions through policy mechanisms.

Participants were asked to indicate their willingness to allow five different levels of interaction with their personal objects using a three-point scale: ✓(Always Allow), - (Sometimes Allow), and × (Never Allow). For the "Sometimes Allow" option, participants were instructed to provide reasons or conditions under which they would permit the interaction.

3.1.3 Interview and Data Analysis. The survey also included questions about various contextual factors that might influence participants' decisions about object access. These factors included the relationship with the potential user, attributes of the object (e.g., monetary value, personal attachment), duration of lending, past experiences with lending and borrowing, and urgency or necessity of use. Participants were asked to rate the importance of these factors and provide explanations for their choices. This approach was designed to gather data on the decision-making process involved in granting access to personal objects in shared MR spaces.

Fifteen minute semi-structured interviews served two primary purposes: to delve deeper into participants' survey responses and to explore specific scenarios in more detail. We focused on elaborating the reasoning behind participants' choices for the five levels of interaction and investigating how the contextual factors (such as relationships, object attributes, and urgency of use) influenced their decisions. Participants were asked to provide concrete examples and explain their decision-making process in various MR-enhanced scenarios.

After obtaining consent from the participants, audio recordings of the interviews were conducted. The analysis of the interview transcripts was carried out through a structured coding process. The objective of these interviews was to explore the types of policies individuals establish when MR applications encourage specific actions involving everyday objects. In this study, the coding process was employed to analyze the collected data. Initially, two coders independently reviewed the transcripts and created individual codebooks aligned with the interview's objectives. Subsequently, the coders shared their codebooks and collaboratively developed a unified codebook. In cases of conflicting codes, discussions were held to resolve discrepancies. Finally, a single coder, well-versed in the codebook creation process, applied the finalized codebook to recode all transcripts for consistency and accuracy (Appendix B.1).

3.2 Results and Analysis

3.2.1 User-Defined Conditions. This study examined how individuals make access control decisions for everyday objects. These decisions were influenced by a range of factors, from broad contexts to specific personal conditions. While some patterns were consistent, many decisions reflected unique, individualized considerations. Interestingly, our study uncovered several additional factors beyond the conditions identified by Jenkins et al. regarding borrowing and lending. These factors—Relationship, Attribute of Object, Time, Past Borrowing and Lending Experience, and Need and Urgency—were also found to include more detailed sub-factors, revealing greater complexity than initially described [49]. The findings are summarized below, highlighting both commonalities and nuanced perspectives.

Environmental Context: Access rules were often situational and adapted to emergencies or practical needs. For example, P1, despite disliking others touching their cup, acknowledged it might be necessary "if it's in the sink and in the way." Similarly, P7, who generally imposed strict rules on devices, allowed exceptions for emergencies, such as "calling 911" or meeting urgent deadlines. Extreme conditions, like heavy rain or typhoons, led participants like P3 to permit object destruction, while P6 allowed disposal of expired items. These examples demonstrate the fluidity of access rules in response to circumstances.

The social and physical environment also shaped decisions. In shared spaces like a "free-address office," P12 imposed stricter rules, whereas in controlled environments like a laboratory, P6 believed access was implicitly granted to those allowed entry. Proximity played a role as well, with P1 preferring to manage items personally when present but adopting more lenient policies when absent. These findings underline the influence of space, social dynamics, and supervision on access control.

Human-Related Factors: Relationships significantly impacted access control, with trust and familiarity as key determinants. P9 emphasized that "trust and closeness" were critical, and P7 distinguished between classmates they knew well and those they did not. Even trusted individuals faced boundaries, as noted by P10, who allowed more limited access to strangers compared to friends. Communication further influenced decisions. P1 preferred requests to be explicit, stating, "I'd prefer it not to be used without asking," while P5 expanded permissions when intentions were clearly explained. These results highlight the interplay of trust, familiarity, and communication in access negotiations.

Object-Specific Factors: The perceived value of an object heavily influenced permissions. Participants like P13 were more lenient with consumables but cautious with durable goods, while P12 imposed stricter rules for expensive items. Specific conditions also affected decisions. P6 allowed disposal of spoiled items, and P1 adjusted policies based on wear and tear. The intended use of an object often defined boundaries, with participants distinguishing between minor and significant modifications. For instance, P13 permitted slight changes, but P5 rejected substantial alterations. Additionally, participants like P1 emphasized the importance of functionality over the object itself, underscoring a focus on the practical implications of access.

The duration of access also mattered. P1 allowed short-term lending but avoided prolonged absence of items, and P8 noted that frequent use by others could limit their access to shared objects. These considerations reflect the dynamic nature of access decisions based on object-specific factors.

Safety and Hygiene: Concerns about cleanliness and potential risks were significant. Items with close physical contact, like mugs, were rarely shared, as noted by P1, who stated, "I wouldn't lend items like mugs." Hygiene standards also extended to less personal items, with P6 emphasizing cleanliness for books. Additionally, participants worried about damage or relational strain, with P4 cautioning against lending, referencing the saying, "If you lend money, don't expect it back." These considerations highlight the role of safety and relational harmony in access decisions.

Experiential Factors: Past experiences shaped access policies. Negative encounters, such as damaged returns, led to stricter rules, as P12 noted, "bad experiences did influence me." Conversely, P11 reported leniency due to a lack of negative incidents. Participants also referenced common sense in their decisions, such as P2's stance against object modifications, though interpretations varied. For example, P3 deemed it acceptable for umbrellas to break under regular use if unintentional. These findings illustrate how experiences and shared norms inform access control decisions.

Participants occasionally referred to common sense to justify their decisions. P2 noted that object modifications were generally unacceptable, stating, "everyone would probably say no." However, individual interpretations varied, as P3 found it acceptable for umbrellas to break under regular use, provided the damage was unintentional.

3.2.2 Survey Insights and Gaps. Access control is often guided by the general principle that "permission is required before touching someone else's property." While policies adhering to this expectation can be modeled incrementally, such as ✓-xxx or ✓–xx, these frameworks do not universally apply to all individuals or objects, as illustrated in Figure3. Although ownership is widely understood, its application varies significantly among individuals.

For instance, while most participants selected "always" for actions involving use without contact, some chose "never." Conversely, actions like giving and discarding, typically marked as "never," occasionally received "sometimes" or "always." These results demonstrate the difficulty of designing uniform policies that apply equally to all people and objects, even for seemingly straightforward actions.

Framework Insights The study's framework suggested that permissions for one action could imply permissions for related actions. For example, allowing contact often implied use without contact, and permitting giving or discarding frequently aligned with modification. However, exceptions were evident. P12, for instance, allowed the conditional discarding of Mint Candy wrappers if empty but prohibited any form of modification, citing hygiene concerns. They found it uncomfortable for others to alter an item they had personally used, preferring its immediate disposal instead.

These findings indicate that higher-level actions, such as discarding, do not always imply permission for related lower-level actions, such as modification. This highlights the importance of accounting for exceptions when designing access control policies.

Insights from Interviews Interviews revealed additional considerations not captured in the initial survey. For example, P2 mentioned granting cleaning staff special permissions, and P4 highlighted unique rules for collector's items. These insights show the complexity of access control, shaped by context and object-specific factors. In IoT research, it is well established that non-experts often struggle to create practical settings independently [48]. MR environments similarly benefit from additional expert support [74]. While access control for everyday objects involves lower expertise compared to security-critical systems, interactive support or conversations can help capture users' true intentions more effectively. This assistance can also aid in refining policy design.

3.3 System Requirement

These findings align with prior research documenting similar complexities [41, 49]. For example, P1 noted, "Since I answer with the current reality in mind, it tends to translate into how people lend things," suggesting parallels between real-world lending and mixed-reality (MR) environments. Participants reported that MR applications involve equally intricate considerations, mirroring real-world challenges.

Additionally, MR-specific access control introduced unique issues. Some participants expressed discomfort with granting visibility to certain MR elements, as they felt uneasy about drawing attention through shared digital information. Others imposed restrictions on physical interactions like touching, depending on the context. These findings illustrate how MR environments create novel scenarios that intertwine with real-world norms, complicating decision-making. This interplay between familiar real-world principles and MR-specific considerations underscores the multifaceted nature of access control, necessitating flexible and context-sensitive policy designs.

Based on these findings, we defined three key requirements for access control systems of everyday objects:

(1) **Granular Policy Description:** Our study revealed that access control decisions in MR environments are highly nuanced and context-dependent. Participants often described complex scenarios where their willingness to grant access depended on intricate combinations of factors. To address this complexity, the system must support the creation and management of highly detailed and nuanced policies.

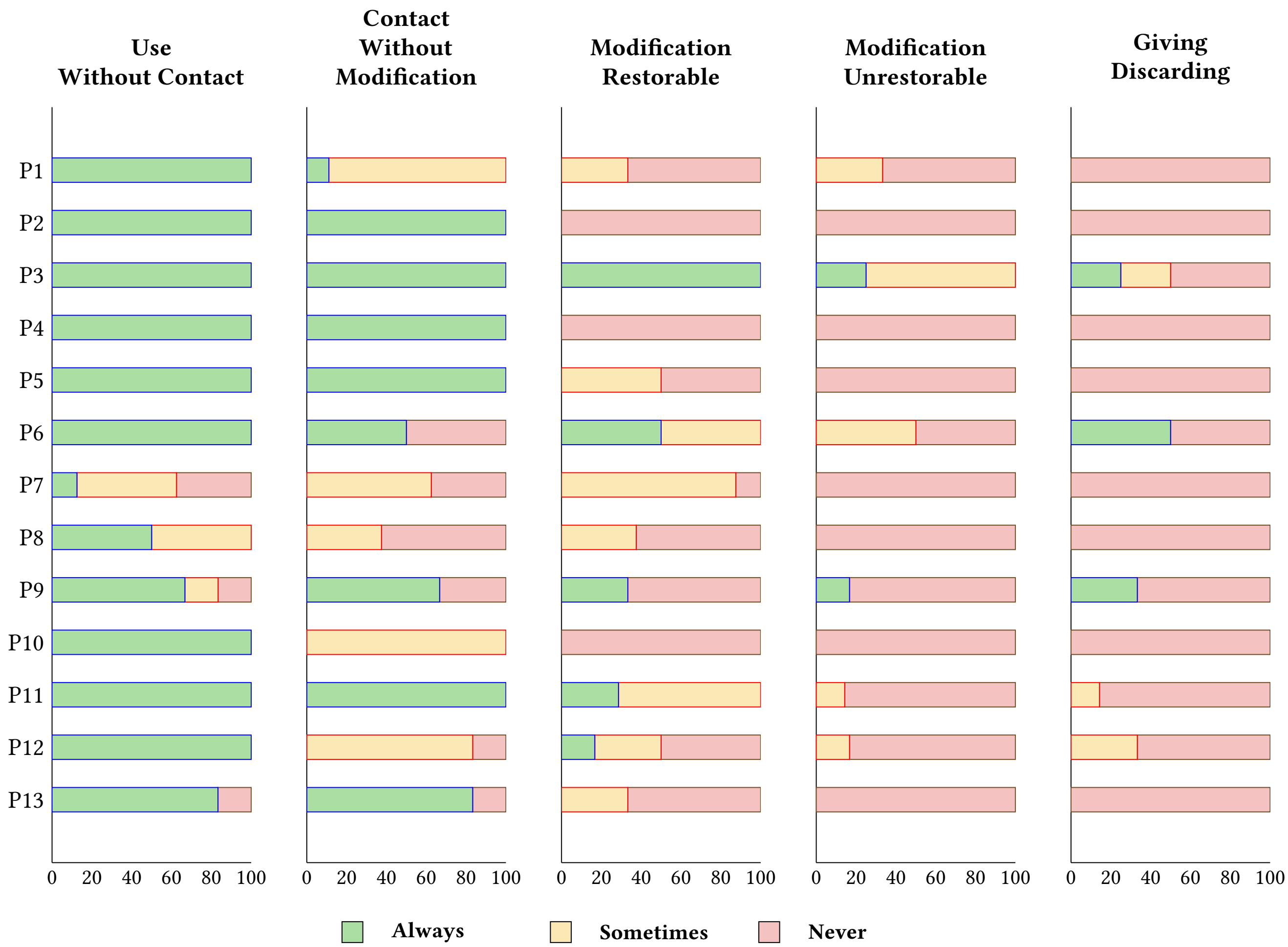

Figure 3: The graph shows the percentage distribution of responses (Always, Sometimes, Never) for five levels of actions (Action 1 to Action 5) across participants P1–P13. The horizontal axis (0–100) represents the percentage of responses, with green indicating "Always," yellow representing "Sometimes," and red denoting "Never."

(2) **System-level Policy Comprehension:** Access control in MR environments is highly context-dependent, with decisions often shaped by a complex interplay of situational, relational, and object-specific factors. A system capable of capturing and managing such nuanced and detailed policies is essential to reflect the complexity of real-world scenarios and adapt effectively to diverse user needs.

(3) **Interactive Policy Creation:** Users often struggle to anticipate all the factors influencing their access control decisions. An interactive, dialogue-based system would guide them to refine their policies by addressing overlooked details and adapting to unique contexts. This approach ensures that access rules are not only comprehensive but also accurately represent users' intentions.

4 Prototype System

To investigate optimal access control mechanisms for everyday objects, we developed a prototype system that meets three key requirements. This system allows users to experience and evaluate various forms of access control, addressing the limitations of traditional approaches while accommodating the nuanced nature of everyday interactions with objects. Similar to Section 3, this system first guides users to register access control policies and subsequently conducts an interview-style dialogue to further refine and explore the registered policies.

4.1 System Overview

The system architecture maintains the standard XACML components [7]: the Policy Enforcement Point (PEP) serves as the request interface; the Policy Administration Point (PAP) facilitates policy creation and management; the Policy Decision Point (PDP) evaluates requests against policies; and the Policy Information Point

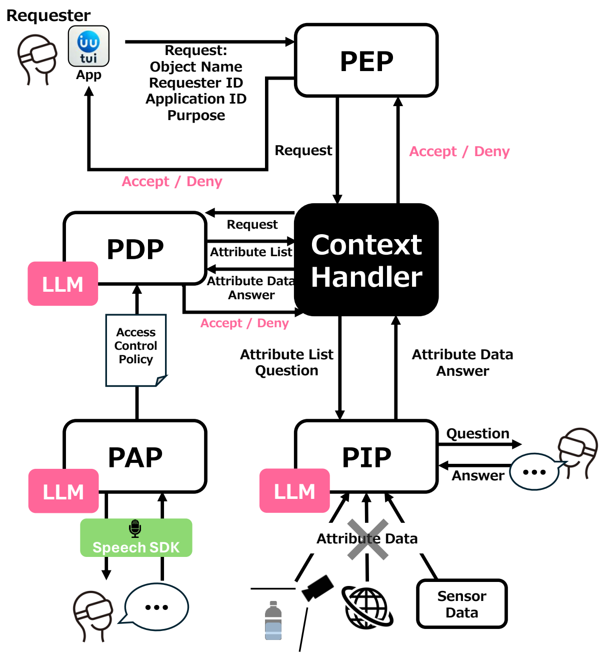

Figure 4: Access Control Data-flow Diagram. The requester sends a request through the application and receives an Accept/Deny decision. Each of the PAP, PDP, and PIP modules integrates an LLM. The owner interacts with the agent in two main instances: first, when registering a policy at the PAP, and second, when answering questions at the PIP that provide additional information necessary for making a decision.

(PIP) provides necessary information for PDP's decision-making. To enhance the system's capability in handling complex policies, we have integrated LLM-powered modules into the PAP, PDP, and PIP components.

Interactive Policy Creation in PAP: The system engages users in conversations by posing prompts designed to clarify the five-step process for defining access control policies. This dialogue is facilitated by a LLM, which serves as the system's interface. One notable feature of the system is its ability to ensure policy consistency during the dialogue. It checks for any potential conflicts or changes introduced by another user mid-session. To maintain brevity and user engagement, the conversation is restricted to single-question exchanges, which are terminated once sufficient information is gathered to meet the five-step actions (Use-Without-Contact, Contact-Without Modification, Modification-Restorable, Modification-Unrestorable, Giving-Discarding). Additionally, users are provided the opportunity to make provisional edits. The system asks users directly whether any part of the generated policy needs to be altered, allowing for quick and efficient adjustments.

Granular Policy Description in PDP: In this prototype, policies are stored in their original natural language form rather than being converted to a predefined markup language. Based on interviews and user feedback, we found that the contexts surrounding access control policies often involve complex and detailed nuances that existing access control policy languages struggle to capture.

Understanding and Executing Policies in PIP: The final requirement emphasizes the system's ability to understand the complex policies stored in natural language and take appropriate actions. The system must interpret ambiguous expressions while leaving them open to user clarification. For instance, it must decide whether to inquire directly with a user when it is unclear whether permission has been granted or whether certain conditions apply (e.g., if a user has a cold). This capability enables the system to ask follow-up questions and act based on the user's responses, thus facilitating smooth policy enforcement in real-world scenarios. In this prototype, given that the contexts available from HMDs are not yet standardized across companies, the system does not retrieve context from the internet or sensor data when parts of a policy are ambiguous. Instead, it treats all such cases as 'nothing' and prompts the user for clarification.

4.2 Access Control Policies Written in Natural Language

In the previous section, we described that this study maintains access control policies in natural language. By introducing access control policies composed in natural language, we can flexibly respond to complex conditions, and while being static policies, they can be dynamically modified by reloading them into an LLM. Conventional static access control policy description methods, once conditions are finely determined, can strictly judge policy permissions and denials according to those conditions. Therefore, they were very suitable for managing file operations such as open, edit, and delete, as well as controlling human traffic access.

However, the case of everyday objects with many complex and ambiguous conditions presents unique challenges. Consider the following access control policy for a bottle. Figure5 illustrates expressions that traditional markup languages, which excel at clearly describing conditions, struggle with.

> All family members are allowed to touch this bottle.
> If the bottle is still cold, actions that may cause it to lose its coldness, such as holding it for a long time or shaking it vigorously, are not allowed.
> Any modifications or discarding of the bottle require the owner's permission.
> Once the bottle is empty or has spoiled, it is free for anyone to use.

Figure 5: Example of a policy written in natural language. Green highlights sensing challenges, such as determining if the bottle is still cold; red marks ambiguities requiring the owner's permission, like discarding or modifying the bottle; and blue indicates future uncertainties, such as when the bottle is empty or spoiled.

Determining whether "the bottle is still cold" presents a significant challenge due to the inherent difficulty of sensing such conditions in everyday contexts. Unlike specialized devices, bottles typically lack embedded temperature sensors, making it impractical to automate this determination. Even if sensing mechanisms were available, the definition of "cold" is highly subjective, varying among individuals and contexts. This subjectivity introduces further complexity for policy enforcement, as the system would need either user input or a standardized threshold to resolve ambiguities. In the absence of reliable sensing data, the system must rely on manual clarification from users, potentially disrupting the fluidity of interactions.

The condition "actions that may cause it to lose its coldness" introduces additional ambiguities, as it requires subjective interpretation of which actions fall into this category. For instance, actions such as holding the bottle for an extended period or shaking it vigorously could vary in their perceived impact on the bottle's coldness, depending on the user's judgment or environmental factors. The lack of quantifiable criteria makes it difficult for a system to determine whether such actions violate the policy without directly querying the user. Similarly, the requirement that "any modifications or discarding of the bottle require the owner's permission" highlights ambiguities in the method of obtaining and validating this permission. Policies relying on owner permission assume direct communication between the requester and the owner, which may not always be feasible. Situations where the owner is unavailable or the request is implicit further complicate enforcement. Systems would need to address these nuances dynamically, balancing the preservation of social norms with operational efficiency.

The condition "once the bottle is empty or has spoiled, it is free for anyone to use" exemplifies the challenges posed by future-oriented and context-sensitive policies. Determining when the bottle is "empty" or "spoiled" depends on situational and subjective factors, such as the frequency of use or individual perceptions of spoilage. While detecting an empty bottle might be straightforward, identifying spoilage involves sensory cues like smell or taste, which are not easily captured or standardized. Furthermore, the timing of these transitions introduces temporal ambiguity, as the system must decide at what point the policy shifts from restricted to unrestricted use. These challenges underline the necessity of systems capable of handling evolving conditions and integrating user input to resolve uncertainties in real time.

Originally, access control was a system for strictly managing these aspects. Therefore, system-like behavior was suitable for it. In comparison, access control for everyday objects is inherently ambiguous and complex. In this system, we decided to use access control policies as they are in natural language, which allows for judgment while retaining this ambiguity.

4.3 Access Control Workflow

Figure 6 illustrates the interface of our prototype and its usage methodology. The primary interaction mechanism for users is a centrally located chat UI, through which they engage in dialogue with an agent to register and edit policies. Virtual buttons and objects within the interface are designed for direct manipulation by the user's hands. This dual-mode interaction approach combines conversational AI for complex policy management with intuitive gesture-based control for simpler interface elements.

Object Registration The process is initiated when a user identifies an object absent from the system's database. Utilization of a "Register New Objects" function triggers a voice-activated registration protocol. Upon verbal input of the object's nomenclature and subsequent verification, the system generates a visual representation—a green skeletal structure—signifying successful registration.

Spatial Positioning Following registration, the user engages in a spatial positioning exercise. The system's interface allows for manual manipulation of the object's digital representation, including translational movement and scalar adjustments. This phase culminates in the activation of a policy window, which is achieved through tactile interaction with the digital object.

Policy Formulation Policy formulation is facilitated through a dialogue-based interface. An intelligent agent initiates a series of inquiries pertaining to the desired management protocols for the registered object. This iterative process continues until a comprehensive policy, encompassing five distinct action stages, is formulated. The system then presents the aggregated policy for user review, allowing for further refinement if necessary.

Policy Verification The final phase involves empirical verification of the established policy. This is achieved through the simulation of access requests via the PEP. The system's response is bifurcated: autonomous decisions are made in scenarios where user input is unnecessary, while interactive questioning is employed when additional context is required. User feedback in this phase is primarily voice-based, ensuring a seamless and intuitive verification process.

4.4 Implementation

The application was developed using Unity 2021.3.21f and Visual Studio 2022. It targets the Microsoft HoloLens 2 platform. Mixed Reality Toolkit (MRTK) version 3 was used for mixed reality features. Voice recognition was implemented with Azure Speech SDK. The application integrates ChatGPT-4-mini for AI functionalities.

5 Evaluation

This study's evaluation has two main objectives. The first objective is to comprehensively cover all system requirements, generate complex policies, and deepen their content through dialogue-based interactions. We aim to observe users' impressions of such a system, evaluate its usability, and examine how users engage in the policy registration process, as well as their willingness to define detailed policies. By observing these aspects, we aim to understand the trade-offs between convenience and accuracy. The second objective is to collect and organize users' preferences for an access control system they would want to use. By having participants interact with the system while wearing an HMD, we also aim to gather their overall impressions regarding access control and discuss how access control systems should be implemented.

5.1 Procedures

We recruited 12 participants from a local community. The group consisted of nine males and three females, with an average age

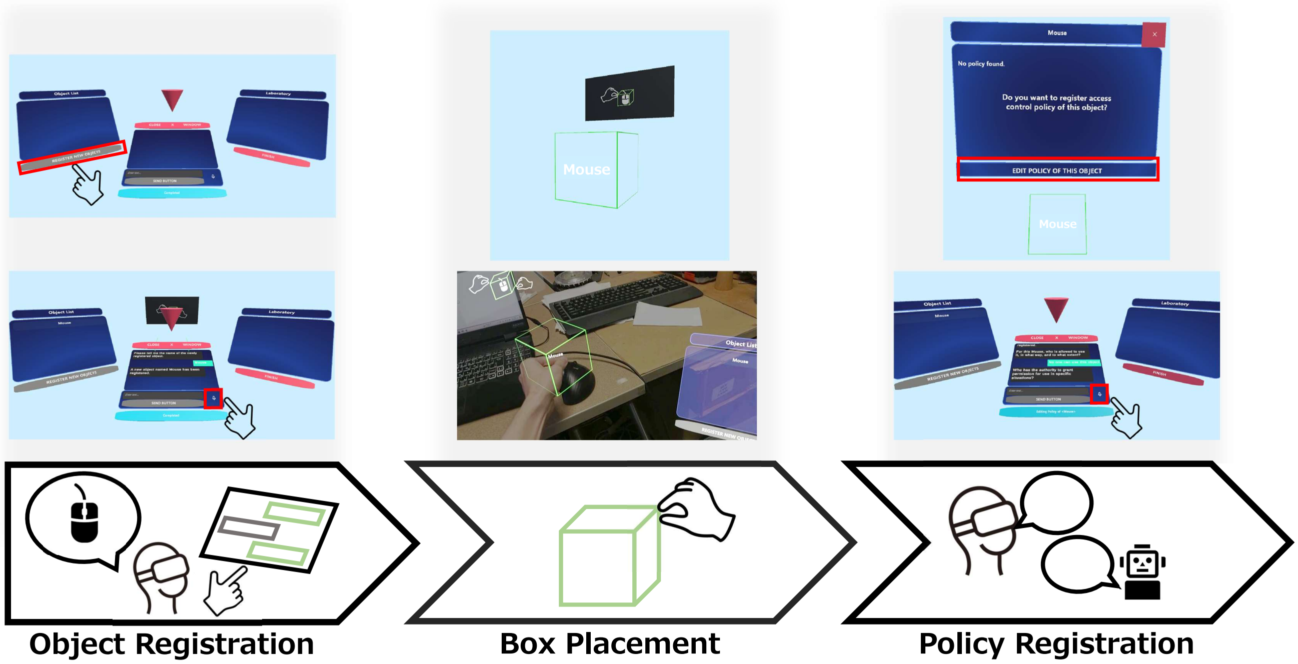

Figure 6: Access Control Policy Registration Workflow. This process consists of three major steps. 1) The user engages in a dialogue with the agent to register a new object. 2) A green box with the registered object's name will appear, which the user then drags and places over the object they wish to register a policy for. 3) The user touches a button on the policy window and engages in several dialogues with the agent. Based on these conversations, the policy is registered.

of 22.25 years. Participants provided informed consent after being briefed on the study's purpose, procedures, and their rights, including privacy protection. To minimize bias, they were also informed that the system was a prototype and encouraged to provide honest feedback, including negative opinions [97]. Before the experiment, participants were asked to rate their AR/VR experience on a five-point scale. The results showed that one participant had *no experience*, five were *beginners*, four were *intermediate*, one was *advanced*, and one was an *expert*.

5.1.1 Process. The experiment was conducted individually with the following steps:

Introduction: Participants were introduced to the HoloLens and XR-based TUIs, including potential risks and examples of issues arising from a lack of access control. Instructions on operating the HoloLens 2 were provided.

Pre-experiment Questionnaire: Participants listed everyday objects they would bring to three shared spaces (Living Room, Workspace, Cafe Lounge) and described their significance. They also imagined potential risks and specified how these objects should be protected.

Main Procedure: Using HoloLens 2, participants registered objects and policies through a chat agent with voice recognition. Policies were registered without restricting the objects. Scenarios were presented in random order, and participants completed policy registration for each scenario.

Post-experiment Policy Review: Participants evaluated the system under three configurations: *All Permit* (no restrictions), *All Deny* (strict privacy protection), and *Policy System* (user-defined policies). These configurations aimed to demonstrate the trade-offs between convenience and accuracy in access control. The prototype system processed requests derived from applications classified into five action levels (3.1.1) based on the policies created by participants, outputting permissions or denials. Participants then reviewed these results and rated the system on convenience, acceptability, and willingness to use on a five-point Likert scale.

Post-experiment Questionnaire: Participants completed a questionnaire using the System Usability Scale (SUS) to evaluate usability. They also rated the systems on convenience, acceptability, and suitability for daily use on a five-point scale.

Post-experiment Interview: Semi-structured interviews were conducted to explore participants' impressions of the policy registration process, the differences between registered and unregistered objects, and their preferences for an ideal access control system. Similarly, we followed the coding process outlined in Section 3, and created code book on Appendix B.2.

5.2 Results

5.2.1 Usability Questionnaire. Figure 7 shows the results of the usability questionnaire. The analysis of user feedback reveals a nuanced understanding of the system's usability, derived from both quantitative metrics and qualitative comments. Overall, users expressed moderate levels of interest and satisfaction with the system, as evidenced by the average scores across metrics, while variability in responses highlighted differing user experiences.

The Desire to Use metric (AVG 3.5, SV 1.0) reflected a moderate level of interest in adopting the system. Participants such as P6 acknowledged its value for ownership management, stating, "This system is not about being easy to use but about managing ownership properly, which makes it worthwhile." However, others found the setup process complex, with P2 describing it as "involving too many steps for everyday use," which may have reduced its initial appeal. Similarly, the system was perceived as less intuitive, with the System Straightforward metric (AVG 3.08, SV 1.44) scoring relatively low. Variability in responses suggests that prior familiarity with similar systems played a significant role. Experienced users like P1 found it easy to navigate, stating, "Since I use similar systems regularly, I had no trouble operating it." In contrast, P7 highlighted challenges for beginners, remarking, "It's particularly challenging for people who aren't familiar with AR." These comments point to a need for more user-friendly design elements, particularly for novices.

While participants found certain aspects convenient, such as structured guidance (noted by P6: "You can complete the setup without fully grasping every detail."), many identified inefficiencies in the process. The Ease of Use score (AVG 3.25, SV 0.75) and feedback like P2's remark, "The process of inputting information and confirming it felt lengthy," highlight the balance between step-by-step guidance and perceived tedium. For the Well Integrated metric (AVG 3.83, SV 1.11), the ability to clearly define ownership was appreciated, as reflected in P4's comment: "The ability to clearly define ownership myself provided a sense of security."

Variability in user confidence, as shown by the Confident Use metric (AVG 3.25, SV 1.54), highlights differing comfort levels with the system. Experienced users like P1 reported smooth operation, while P11 noted, "I'm still not used to interacting with AR objects," underscoring the need for adaptable support features. The Smooth Operation score (AVG 3.17, SV 1.19) further illustrated mixed experiences, with P9 commenting, "Recognition didn't work well at times, and I had to redo it multiple times." One consistent trend across feedback was the distinction in managing high-value versus low-value items. High-value items were often managed more strictly, as described by P4: "Errors are less tolerable for high-value items." This sentiment is supported by the Consistency metric (AVG 3.92, SV 1.08), with users appreciating the system's structured approach. At the same time, participants such as P6 noted that registering policies for low-value items felt unnecessary unless specific risks were present.

5.2.2 Comparison of System Configurations. A Kruskal-Wallis test was conducted to evaluate whether participants' ratings of convenience, acceptability, and willingness differed significantly across the three systems (Prototype, All Permit, and All Deny). The analysis revealed significant differences for convenience, $H(2) \approx 17.40, p < 0.001$, acceptability, $H(2) \approx 14.49, p < 0.001$, and willingness, $H(2) \approx 6.52, p < 0.05$.

To explore these differences further, Dunn's post-hoc tests with Bonferroni correction ($\alpha = 0.05/3 \approx 0.0167$) were applied. For both convenience and acceptability, Prototype and All Deny differed significantly from All Permit ($p < 0.01$ for both comparisons). This indicate that participants' ratings on these dimensions clearly distinguished All Deny from the other two systems. However, no significant differences were observed between Prototype and All Deny for either convenience or acceptability. Regarding willingness, while the Kruskal-Wallis test suggested a marginally significant difference among the three systems, pairwise comparisons did not reveal significant differences after applying the Bonferroni correction.

The results indicate that the All Permit condition was consistently perceived negatively by participants, reinforcing that a fully permissive policy is not a viable option. In contrast, the All Deny condition did not show significant differences in user impressions compared to the Prototype, suggesting that its impact was less pronounced than expected.

5.2.3 Feedback on the Conversational Agent. One key advantage of the conversational agent is its ability to simplify complex configurations through a natural language interface. Many participants found this feature approachable, as it allowed them to define policies without prior knowledge of access control systems. For example, P2 described the process as "quite fun" and appreciated the ability to assign information to objects, calling it "intriguing." This novel approach lowered the learning curve and encouraged broader participation. The agent's structured dialogue also guided users step-by-step, ensuring no critical details were overlooked. P4 emphasized the value of follow-up questions for detailed registrations, while P6 noted that this approach allowed them to proceed without fully understanding all settings upfront. Some participants, such as P12, found voice input convenient, particularly for adding long descriptions incrementally, which reduced manual effort.

However, several limitations were identified. Some users found the agent's prompts overly formal or unclear, making it difficult to understand the expected scope of responses. P10 expressed confusion over whether to address "time," "people," or "the object's operational state," while P1 described the formal phrasing as "daunting." Additionally, the structured dialogue, while thorough, felt overly time-consuming due to repeated confirmation steps. P2 described the process as "lengthy," and P12 noted that registering items took

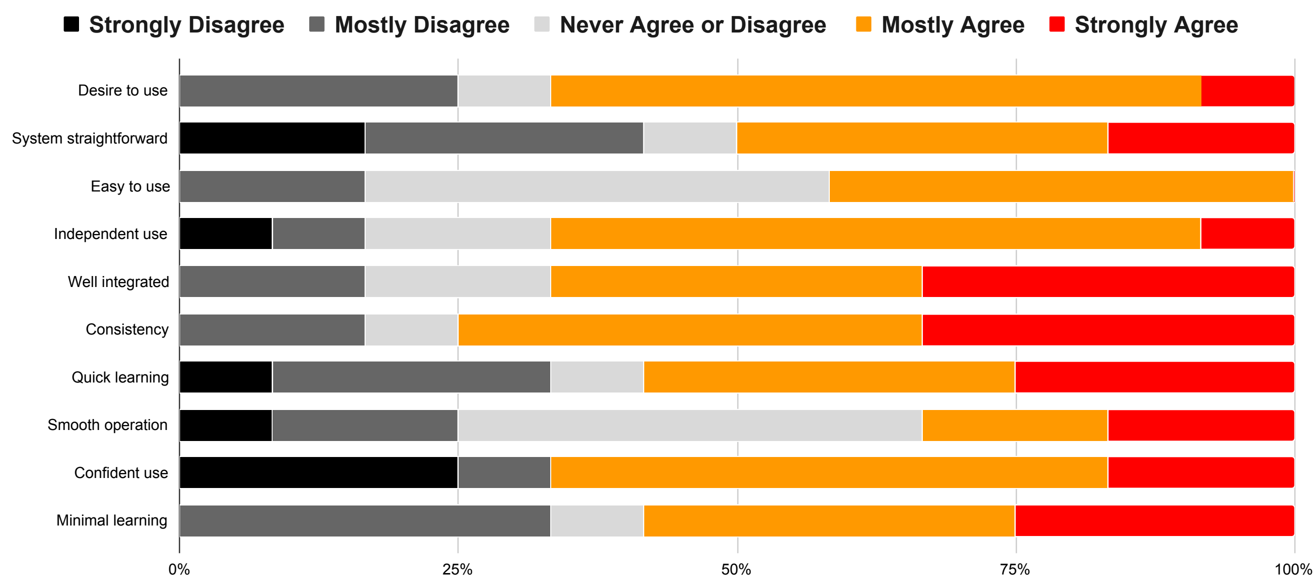

Figure 7: System Usability Scale Questionnaire Results

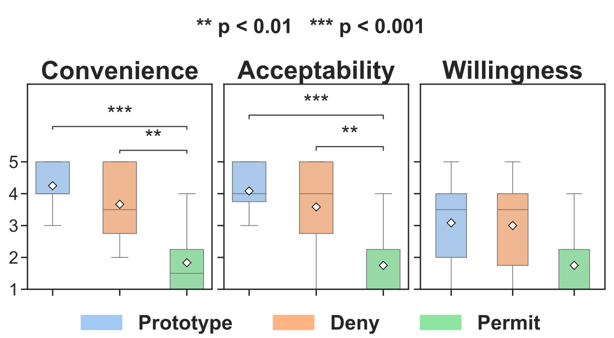

Figure 8: The figure shows ratings of Convenience, Acceptability, and Willingness across Prototype, All Deny, and All Permit. Prototype scored highest and Permit lowest for Convenience and Acceptability (* $p < 0.001$, ** $p < 0.01$), while Willingness showed no difference between Prototype and Deny.**

longer than expected. Redundancy in interactions could pose a barrier to daily use. Moreover, the system's limited ability to infer user intent led to frustration. Participants suggested simpler presets or casual expressions to streamline frequent requests. Finally, the registration process was criticized for being tedious. P5 found configuring a single item cumbersome, and P8 highlighted the inconvenience of manually adding items in dynamic environments. Predefined patterns or customizable shortcuts could address these usability challenges.

5.3 Discussion

5.3.1 Value of Policy Settings. The policy settings in this study reflect conditions similar to those discussed in Section 3. These settings are not solely dependent on the objective value of the objects but also take into account emotional value and their perceived importance.

For some of the objects brought by users, no policies were assigned (Table 2). These objects tended to have lower value or shorter life cycles, such as disposable products, and were often deemed acceptable to handle with minimal care. Many participants responded that they would not mind if these objects were treated casually. However, when asked whether they would tolerate such objects being tampered with or deformed without permission, they expressed discomfort. This shared understanding was supported by the fact that systems employing an "All Permit" approach were widely disliked compared to others, emphasizing participants' aversion to allowing unrestricted handling.

In contrast, for objects deemed important by participants, it was almost universally unacceptable to touch them without explicit permission. Even visual access was often subject to strict conditions, and none of the participants configured policies that allowed unrestricted handling of these objects. Therefore, for important objects, default denial of access may be the most practical approach to avoid potential issues. However, while this approach aligns with user expectations, it presents a challenge from the perspective of application developers and system operators. Overly strict default settings may constrain application users' interactions with objects and limit designers' ability to implement functional and flexible experiences. Therefore, such restrictions should be carefully considered to avoid unintended limitations.

ID	Gender	Age	Shared Space	Relationship	Objects
1	Female	21-25	Living Room	Family	Smartphone, (Earphones), (Scarf), (Gloves), (Water Bottle)
			Workspace	Colleague	Smartphone, PC, (Snacks), Book
			Cafe Lounge	Friend, Acquaintance	Smartphone, Wallet, (Jacket)
2	Male	21-25	Living Room	Friend	Water Bottle, PC, Book, Tablet Device, Game Console
			Workspace	Friend, Lab Member	PC, Book, (Water Bottle)
			Cafe Lounge	Friend, Other Users	PC, Book
3	Male	21-25	Living Room	Mother, Father, Girlfriend	Tablet Device, Smartphone, Laptop, Monitor, Game Console
			Workspace	Lab Member, Professor	Laptop, Tablet Device, Smartphone, Earphones
			Cafe Lounge	Some Random People, Friends, Mother, Father	Cafe Cup, Smartphone, Earphones
4	Female	21-25	Living Room	Family	PC, Bottle, Smartphone, Pencil Case
			Workspace	Lab Member	PC, Bottle, Pencil Case, Smartphone
			Cafe Lounge	Strangers	PC, Smartphone
5	Male	21-25	Living Room	Father, Relatives, Parent's Friends	PC, Bottle
			Workspace	Colleague, Manager	PC, Electronic Components, (Cookies)
			Cafe Lounge	Friends, Dormitory Residents, Strangers	Water Bottle, Smartphone
6	Male	21-25	Living Room	Father, Mother, Siblings, Girlfriend	Smartphone, Carbonated Drink, Mug Cup
			Workspace	Boss, Colleague, Lab Friends, Professor	Laptop, Smartphone, USB Hub, Coat, Bag, Water Bottle
			Cafe Lounge	Friend, Girlfriend, Acquaintance, Stranger	Smartphone, Water Bottle, Coat, Bag
7	Male	26-30	Living Room	Father, Siblings, Friends	Smartphone, Glasses, Wallet, PC
			Workspace	Colleague, Boss, Strangers	PC, Notebook, (Gloves), (Bottle)
			Cafe Lounge	Friends, Clerks, Strangers	Sweets, Magazine, (Bottle), (Plate)
8	Male	18-20	Living Room	Friends, Family	Snacks, Water, (Tea), PC, (Console), (Pen), (Book), (Toys)
			Workspace	Colleague	Water, Snacks, PC, Smartphone, (Toys)
			Cafe Lounge	Friends	Water, PC
9	Male	18-20	Living Room	Parents, Siblings, Friends	Smartphone, Watch, Bottle, Wallet
			Workspace	Colleague, Boss, Subordinates	PC, Documents
			Cafe Lounge	Friends, Clerks, Other Customers	Smartphone, Bag
10	Male	21-25	Living Room	Father, Mother	Mug Cup, (Plate), PC, Ice Cream, (Spoon)
			Workspace	Colleague, Boss, Client	Paper Cup, PC, Documents, (Candy)
			Cafe Lounge	Clerks, Other Customers	Tea, (Cake), Smartphone
11	Female	21-25	Living Room	Parents, Siblings, Mother's Friends	Smartphone, Bottle, Pen
			Workspace	Lab Members, Professor	PC, Bag, Glasses
			Cafe Lounge	Friends, Strangers, Clerks	Smartphone, Bag, Coat
12	Male	21-25	Living Room	Friends	Smartphone, Cup, Dishware, (Drink), Cigarette, Lighter, Air Conditioner Remote
			Workspace	Lab Members, Colleagues, Boss	Smartphone, Cigarette, Lighter, Snacks, Laptop, Wallet, Watch
			Cafe Lounge	Clerks, Friends	Drink, Smartphone, Cigarette, Lighter, Laptop, Wallet

Table 2: Participant data with shared spaces, relationships, and objects. Objects that participants did not register policies for while using the prototype are enclosed in () parentheses.

For consumable items or objects of lesser value, preferences varied widely. Some participants insisted on policies as strict as those for important objects, while others allowed conditional handling or even minor modifications. There were also those who prioritized preventing disposal but otherwise had few concerns about handling. These diverse attitudes resulted in a broad range of policy preferences for these types of objects.

The motivation for setting policies also differed among users. Some found it cumbersome to set detailed policies for every item or to create new policies every time additional items were introduced into daily life. Others, however, valued ownership and access control highly enough to tolerate the associated effort. Ideally, systems should offer customizable solutions to match user preferences: allowing those who desire detailed control to configure policies comprehensively, while providing streamlined, low-effort options for users who prefer simplicity. Importantly, even for users who require more detailed customization, automation could help alleviate the burden by simplifying the process of policy registration through learning from past behavior.

5.3.2 Ideas for an Ideal Access Control System. During interviews, participants shared their thoughts on what kinds of access control systems they would find useful, excluding the current system we are working on. Below is a summary of their ideas, presented in order:

Universal Restriction / Copy and Paste: This system applies universal rules across all objects or contexts. Users can, for example, universally prohibit all interactions or allow viewing while restricting physical contact. Although this method requires minimal effort, it lacks flexibility and does not account for specific situations. Despite these limitations, some users appreciated its simplicity. However, from a system development standpoint, overly strict universal policies such as "All Deny" might significantly reduce usability by preventing any meaningful interaction with objects.

Confirmation for Requests: An interface based on making choices in response to access requests, ranging from simple binary decisions to more complex configurations:

- **Binary Choice:** Users respond to incoming requests with a simple "Yes" or "No."
- **Multiple Choice:** Users have intermediate options, similar to a Likert scale, as seen in the questionnaire conducted in Section 3.
- **Bar-Shaped Interface:** Users adjust a sliding node along a bar, setting access preferences dynamically on a scale (e.g., 5 levels or unrestricted granularity).

The burden on users depends heavily on the number of incoming requests, as frequent decision-making could lead to fatigue.

Conversational Agent with Binary Choices: This combines a conversational agent with binary decision-making. Users engage with the agent through text or voice but primarily respond to requests using simple binary options. While this method is convenient for quick responses, creating complex policies or attaching conditions may require manual input. This hybrid approach balances the convenience of automation with user control.

Automated Policy Learning: This system leverages historical user responses and interactions with conversational agents to dynamically generate and update policies. Although incorrect policies may occasionally be created, human verification and adjustments allow for continuous refinement. Once initial data is input, users primarily need to review and adjust policies, reducing the overall workload.

Detailed Policy Adjustments: This option allows users to craft highly specific policies from scratch without relying on conversational agents. While it offers the greatest level of customization, it can be time-consuming compared to other methods. This approach is suitable for users who require precise access rules and are willing to invest the time needed for configuration.

One possible direction for improving access control systems is to combine approaches that reduce the burden of initial policy setup while maintaining user control. For example, pre-configured templates based on common usage patterns might provide users with a practical starting point, minimizing the need for extensive manual configuration. Similarly, adaptive mechanisms that dynamically adjust policies according to context could help users by allowing them to refine policies over time instead of defining every detail in advance. By integrating these approaches, systems could potentially achieve a balance between automation and user oversight, enhancing usability for both casual users and those who prefer detailed customization.

These different approaches illustrate the trade-offs between simplicity, flexibility, and user effort. While some users prioritize low-maintenance systems with universal rules, others require adaptable solutions that cater to specific needs. An optimal system would combine these strengths, offering minimal-effort options while also supporting complex policy configurations when necessary. Achieving this balance—"low effort with complex policy capability"—represents a key challenge for future system development.

6 Limitation

Challenges of XR Devices: In this study, we implemented the system in an MR environment, but it was initially challenging for beginners to use. Furthermore, we utilized speech recognition instead of a keyboard, and when the speech recognition failed to function properly, it left a negative impression. However, as users became accustomed to the system, their registration speed improved significantly. The process of registering policies could mitigate these challenges if conducted over a longer period. While the current study focused only on the initial registration phase, future experiments that involve frequent policy updates or automatic policy generation and adjustments for everyday use should be conducted over an extended period.

Difficulty in Adjusting LLM-Generated Questions: Errors in speech recognition or misidentifying the speaker can result in irrelevant questions being presented to users. Although such occurrences were frequent in this experiment, participants generally managed to redirect the conversation to its intended course when interacting with the agent. Nevertheless, correcting spontaneous errors from the LLM is a substantial challenge. While the conversational aspect helps users articulate their envisioned policies, minimizing these errors is essential. Future use of LLMs for conversations or advice could benefit from pre-filtering frequent errors, thereby reducing the likelihood of such issues to the greatest extent possible.

Policy Dynamics in Shared Spaces: As the system is designed for shared spaces, other individuals' presence must be taken into account when registering policies. In this study, the All Deny condition reflected the unspoken understanding that one should not touch others' belongings without permission, resulting in similar outcomes between All Deny and the prototype. However, witnessing others being denied access to the application or encountering disruptions in daily life might influence individuals to register policies differently in such scenarios. Considering these aspects, future studies should involve experiments over longer periods, including multiple participants wearing HMDs, to better account for the dynamics of shared spaces.

7 Conclusion

This study examined the challenges of managing access control for everyday objects in XR-enhanced shared spaces. The prototype system demonstrated the capability to handle complex, context-dependent scenarios; however, user feedback indicated varying expectations. While some participants valued the system's ability to reflect nuanced preferences, others found the policy setup process overly burdensome, particularly for routine use. These differences emphasize the inherent difficulty in developing access control systems that can cater to diverse user needs.

The results indicate that simplifying the policy management process is a critical area for further development. There is a demand for mechanisms that reduce the initial configuration workload, such as automating parts of policy generation or offering pre-configured templates. These methods would allow policies to adapt over time, supporting both users who prioritize efficiency and those who require more granular control. Designing such approaches is becoming increasingly necessary to improve system usability in shared XR environments. In conclusion, this study highlights the need for access control systems that efficiently support both quick registration and detailed policy management. Future work should focus on refining approaches that strike a balance between automation and flexibility, thereby facilitating broader adoption of XR technologies in everyday shared contexts.

Acknowledgments

We thank all reviewers for their invaluable feedback. This work is partially supported by the NSF under the Future of Work at the Human-Technology Frontier (FW-HTF) 1839971 and Partnership for Innovation: Technology Transfer (PFI-TT) 2329804. We also acknowledge the Feddersen Distinguished Professorship Funds and a gift from Thomas J. Malott. This work is also supported by JST SPRING, Grant Number JPMJSP2123. Any opinions, findings, and conclusions expressed in this material are those of the authors and do not necessarily reflect the views of the funding agency.

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A Questionnaire of Section 3

A.1 Introduction

This survey asks about the relationships you have with people you share your current shared space with, such as an office or laboratory, and the everyday objects you bring into this space. Then, you will be asked under what conditions you would allow people with different relationships to interact with these objects as prompted by a Mixed Reality app. The survey will take approximately 20 - 30 minutes to complete.

In recent years, various companies have released different types of glasses-like devices called Head Mount Displays (HMD). Devices such as Meta Quest 3, and Apple Vision Pro are still fresh in our memories. The promotional videos for these devices showcase usage examples and applications designed for daily life settings like living rooms and offices. The use of such HMDs is expected to increase in the future, and in the field of Human-Computer Interaction, examples utilizing everyday objects in daily life are being presented. One such example is Tangible User Interfaces (TUI). Various examples of Tangible User Interfaces have been proposed, where virtual displays show information on everyday objects like water bottles and cushions, or where the objects themselves are used as interfaces to operate devices.

Imagine you are wearing an HMD and viewing the real world:

- When you look at an umbrella, a pop-up displaying the current weather information appears.
- You rotate a cup to change the TV channel because there is no remote control nearby.
- While playing a Mixed Reality game, you use a math textbook as a shield in the game.
- Cut the origami into a triangular shape and use it as a substitute for a computer mouse.
- When you look at an empty juice can, you see information on when to dispose of it in your area and then throw it in the trash.

TUI can add functions to everyday objects that do not originally have those capabilities, by closely integrating these objects with us. However, current systems rarely consider use in shared spaces where multiple people bring in multiple objects.

In shared spaces, various objects are often borrowed and lent. Imagine yourself borrowing and lending items in a shared space. In these shared spaces, we borrow and lend items through conversations and gestures with others. However, current MR applications do not typically facilitate this kind of interaction. As a result, these systems add virtual objects to suitable physical objects without determining who owns which objects and to what extent others are allowed to use them.

In this survey, we will ask about the types of relationships you have with the people you share your current shared space, such as an office or laboratory, and the types of everyday objects you bring into the space. After that, we will ask about the conditions under which you would allow people with different relationships to interact with the objects you bring, and to what extent you would allow actions prompted by an MR app. The actions prompted by the MR app are as follows:

(1) Use-Without-Contact: Using the object without physical contact.
(2) Contact-Without-Modification: Touching or using an object without altering it.
(3) Modification But Restorable: Intentionally altering an object.
(4) Modification Unrestorable: Modifying an object in a way that cannot be restored.
(5) Giving Discarding: Full permission to do anything with the object. You can also throw it in the trash.

Allowing people in the shared space to access your everyday objects means that interfaces showing information or allowing direct contact with the objects will be displayed. The survey will take approximately 20 minutes to complete.

Your participation in this survey is completely voluntary, and you may withdraw at any time. The collected data will be carefully protected to ensure privacy, used solely for the purpose of this research, and will not be shared with any third parties.

A.2 Question Part

- Which shared spaces do you usually use?
- What kind of relationships do you have with the people you share these spaces with? <Relationship>
- What everyday objects that you own do you bring into these shared spaces? <ObjectName>

For the object <ObjectName>, please answer to what extent (5 levels) you would allow the relationships a to use it under three conditions (✓: always, -: sometimes, x: never).

Relationship	**1**	**2**	**3**	**4**	**5**
<Relationship>	✓ - ×	✓ - ×	✓ - ×	✓ - ×	✓ - ×

- Reasons for "Always" or Reasons for not selecting "Always"
- What are the specific factors for "Sometimes"? When should they be allowed to use this feature? Please be specific.
- In contrast, when should they not be allowed to use this feature? Please be specific.
- Reasons for "Never" or Reasons for not selecting "Never"
- If these persons are allowed access incorrectly, how much of an inconvenience would this be?
- If these persons are denied access incorrectly, how much of an inconvenience would this be?
- Does the relationship with the person affect your decision on whether certain people can or cannot use this particular feature?
- Does the attribute of the object (e.g., price, attatchment) affect your decision on whether certain people can or cannot use this particular feature?
- Does the duration of lending period and other time-related aspects affect your decision on whether certain people can or cannot use this particular feature?

- Does the past borrowing and lending experiences of the object affect your decision on whether certain people can or cannot use this particular feature?
- Does the degree of the other's need and urgency affect your decision on whether certain people can or cannot use this particular feature?
- Do any other specific conditions affect your decision on whether certain people can or cannot use this particular feature?

B Code List

B.1 Code of Section 3

Environmental Context

- Situational Flexibility
  - Emergency
  - Other special conditions
- Locations
- Proximity and Supervision

Human Related

- Relationships
  - Position
  - Trust

Clear Communication

- Permission
- Explanation

Object Related

- Object Importance
  - Value
  - Attachment
  - Private information
- Object State
  - Attribute
  - Condition
  - Expected life
- Part of the object - Contact
- Type of Usage
- Duration and Availability
- Object Affordance

Safety and Hygiene

- Physical and Hygiene Concerns
- Risk Avoidance
- Restorability Condition

Experience

- Past Experiences
- Common Sense

B.2 Code of Section 5

Access Control

- Value of the items
- Cost
- Importance
- Affordance
- Relationships
- Physical and Hygiene
- Locations
- Situational Flexibility
- Experience
- Common Sense

System Value

- Accuracy preference
- Significance of registration
- Use in everyday life
- Trade-offs: inconvenience vs necessity

Usability

- XR Experience Levels
- Intuitiveness
- Straightforwardness
- Flexibility
- Usefulness
- Detailed Policy by conversation
- Step-by-step structure
- Complexity
- First-time confusion
- Redundant process
- Time cost
- Quality of the questions
  - Redundant
  - Irrelevant
  - Unclear terms
  - Lacks common sense

Design Improvements

- Automated policy
- Automated Policy + Human Verification
- Multiple choice
- Visualization
- Confirmation for the requests (Binary Choice)
- Copy and Paste
- More Detailed Adjustment
- Universal Restriction
- Importance bar

Error Tolerance

- All permit
- All reject
- Results of the Prototype System