CENTRIC 2025

The Eighteenth International Conference on Advances in Human-oriented and Personalized Mechanisms, Technologies, and Services

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CENTRIC 2025 Editors

Stephan Böhm, RheinMain University of Applied Sciences - Wiesbaden, Germany

CENTRIC 2025

Forward

The Eighteenth International Conference on Advances in Human-oriented and Personalized Mechanisms, Technologies, and Services (CENTRIC 2025), held on September 28 – October 1, 2025 in Lisbon, Portugal, addressed topics on human-oriented and personalized mechanisms, technologies, and services, commonly known as I-centric.

There is a cohort of technologies that favored the so called “user-centric” services and applications. While some of them reached some maturity, others are to prove their economics (WiMax, IPTV, RFID, etc). The human-oriented and personalized technologies and services rely on a key set of features, some to be deployed, others getting more mature (personal profiles, preferences, identity, proximity, personal devices, etc.). Following, advanced applications covering human related activities benefit from personalized and human-oriented networks and services, especially preventive and personalized medicine, body networks and devices, or anticipative systems.

The conference provided a forum where researchers were able to present recent research results and new research problems and directions related to them. The conference sought contributions presenting novel result and future research in all aspects of user-centric mechanisms, technologies, and services.

Similar to the previous editions, this event continued to be very competitive in its selection process and very well perceived by the international community. As such, it attracted excellent contributions and active participation from all over the world. We were very pleased to receive a large amount of top quality contributions.

We take here the opportunity to warmly thank all the members of the CENTRIC 2025 technical program committee as well as the numerous reviewers. The creation of such a broad and high quality conference program would not have been possible without their involvement. We also kindly thank all the authors that dedicated much of their time and efforts to contribute to the CENTRIC 2025. We truly believe that thanks to all these efforts, the final conference program consists of top quality contributions.

This event could also not have been a reality without the support of many individuals, organizations and sponsors. We also gratefully thank the members of the CENTRIC 2025 organizing committee for their help in handling the logistics and for their work that is making this professional meeting a success.

We hope the CENTRIC 2025 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in personalization research. We also hope that Lisbon provided a pleasant environment during the conference and everyone saved some time for exploring this beautiful city

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Recommendations and Checklists for Developing More Accessible and Comprehensive Browser Cookie Consent Banners

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***Abstract*—We present recommendations and checklists for enhancing the accessibility of browser cookie banners, based on user testing and survey feedback. The study identifies several key challenges, such as lack of clarity, information overload, and manipulative design. We propose solutions, such as standardized language use, simpler interfaces, and preset browser choices to improve both technical and cognitive accessibility. While the study focuses particularly on the needs of people with disabilities, it effectively aims to enable all users to make informed decisions about their privacy online.**

Keywords-Universal Design; ICT (Information and Communication Technology); Web; Digital Accessibility; Usability; User Experience; Browser Cookies; Privacy.

I. INTRODUCTION

Browser cookies are pieces of data stored on a user's device during web browsing to serve functions like login sessions, language preferences, and behavioral tracking [1]. When used to identify users, cookies are classified as personal data and fall under regulations, such as the General Data Protection Regulation (GDPR) and the ePrivacy Directive (EPD), which require informing users about cookie usage and obtaining their consent [2], [3]. Most websites implement browser cookie consent banners, or short cookie banners, to let users accept or reject all or some cookies.

However, cognitive barriers can lead to difficulties and even total exclusion for some users when accessing websites [4], while digital inaccessibility may exclude users, for example with visual disabilities, and those who rely on Assistive Technology (AT) like screen readers [5]. International regulations and standards address this by requiring all components of public websites, including cookie banners, to follow Universal Design (UD) principles and be accessible to all users [6], [7], [8].

Despite their ubiquity, research on cookie banners has mostly focused on usability, with limited attention to technical and cognitive accessibility [9]. This article addresses that gap by examining the UD of cookie banners, especially for users with disabilities and AT users. Based on user testing of Norwegian websites and a survey, we present recommendations and a checklist for accessible design. The article reviews related work in Section II, outlines the methodology Section III, presents findings in Section IV, and offers design guidance in Section V. The appendices include the checklist and prototype images.

II. BACKGROUND

This article builds on a previous study that presented a literature review and expert evaluations of the accessibility and universal design of cookie banners [10]. The review found that most research focused on user interaction and experience, with limited attention to cognitive accessibility. It also highlighted that technical and cognitive issues in multi-purpose dialogs often create significant barriers, especially for users with disabilities. A key finding was the need for user-friendly, transparent design to support comprehension and ethical decision-making.

The expert evaluation revealed issues, such as semantic markup accessibility errors and poor adaptability across devices and screen sizes. Cognitively, banners often emphasized text structure over clarity, complicating interaction. Many banners also failed to receive focus on page load for screen readers. These findings highlight the need to improve both accessibility and understandability in cookie banner design.

III. METHODOLOGY

We conducted user testing and a survey.

A. User Testing.

We conducted user tests with twelve participants with diverse abilities to evaluate the accessibility and usability of cookie banners on four Norwegian website: finn.no [11], bufdir.no [12], skatteetaten.no [13], and facebook.com [14]. These sites represent sectors, such as e-commerce, civil society, public administration, social media, and online services, and were selected based on a preliminary study [10] to reflect diverse banner designs. Banner screenshots are available in [10]. The tests were facilitated by a researcher and conducted both in person and via video conferencing.

A semi-structured interview protocol guided the sessions, combining task-based interaction with "think-aloud" methods and follow-up questions [15], [16]. Participants were asked to locate, understand, and adjust cookie settings. The protocol allowed for brief deviations to obtain in-depth answers on specific (related) topics. This approach provided insights into their cognitive processes and real-time barriers.

Sessions were recorded and analyzed independently by multiple researchers. Observations were synthesized into themes and discussed among all researchers, reflecting both individual user experiences and common patterns, which are summarized in the next section.

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1) User Selection.

The user tests targeted at persons with visual, auditory, physical, and cognitive disabilities. We recruited participants in Norway and Sweden through interest organizations, such as the Norwegian Association of the Blind and Partially Sighted (NABP) and the Pensioners' Association (Pensjonistforbundet), posts on disability-focused online forums on Facebook, and persons registered in the user panel of Stiftelsen Funka.

Twelve users—seven from Norway and five from Sweden—tested the websites. Ages ranged from 15 to over 80. Some had multiple types of disabilities, including no sight, impaired vision, impaired hearing, limited hand manipulation or strength, limited reach, limited cognition, language or learning abilities, and low technology competency.

Users employed various devices, including desktop computers (Windows or Mac with Chrome, Safari, or Edge browsers) and mobile phones (Apple/iOS phones with Chrome or Brave browsers). Assistive technology, such as the VoiceOver screen reader were used by visually impaired users, and one also employed a braille display.

B. Survey

An online survey gathered insights on users' experiences with cookie banners, including ease of reading, consent handling, encountered barriers, and suggestions for improvement. It targeted users with and without disabilities, mainly in Norway and Sweden.

The survey was distributed through civil-society organizations, social media posts(, such as online forums for people with disabilities on Facebook), LinkedIn contacts, and newsletters. Since the survey was sent to an (though thematically limited) undefined audience, it is not possible to calculate a response rate, and the results cannot be considered representative.

IV. RESULTS

"Cookie banner" and "banner" refer to the website interface area containing all cookie and consent elements.

A. User Testing.

We identified three handling patterns among the users:

- Those who consistently accept all cookies (four users).
- Those who, as far as possible, try to reject all cookies (four users).
- Those who choose to accept or reject depending on the context (four users).

All users wanted to handle cookie banners quickly: "I notice them. I do not care about them; I just want to get past them […]." Some ignored banners if they were not intrusive—especially screen reader users.

Several users were unsure what cookies are or why they are needed. About half had a negative view of cookies and banners. None intended to revisit the banner after making a choice, likely because the option was absent on many pages.

No users scrolled to read long cookie texts (e.g., Facebook, Skatteetaten) unless prompted. Many preferred to avoid lengthy settings pages and simply accepted all cookies.

Users found it hard to understand cookie options due to inconsistent wording across sites, requiring repeated learning. Skatteetaten's settings were seen as confusing, with one unclickable checkbox causing irritation. Bufdir's banner was rated clearest, though one user struggled to find it due to its small size, low contrast, and placement in a "blind spot."

Further results are grouped by the four WCAG principles—perceivable, operable, understandable, and robust [17]—plus a section on non-accessibility observations.

1) Perceivable and Robust.

We first examined whether users could detect the banner. Sighted users generally had no issues, though some missed Skatteetaten's banner due to its small size, unusual colors, and graphic design, which made it blend into the page. Most users were not bothered by alternative titles like "Cookie settings" (e.g., Finn).

The experience differed for screen reader users. When the page loaded, VoiceOver (VO) skipped the blocking banner (except on Bufdir) and jumped to the main content, which was unintended since the banner was no longer blocking. It was only detectable using the touch method, where the screen reader reads what is under the user's finger. Some guessed the banner was at the bottom (e.g., Finn), but older users often did not know this. A few appreciated navigating without blocking banners, but we argue banners should be equally perceivable and blocking for all, ideally placed at the top in semantic order (e.g., Skatteetaten). Moreover, two screen reader users noted that after clicking on the banner link, focus landed on the dialog text instead of the heading, causing confusion about their current position within the webpage.

Older users also struggled with inconsistent color palettes and unclear graphics (Skatteetaten), mistaking them for ads ("nagging," "disturbing"). We recommend consistent colors and simple, intuitive icons. On Facebook, the settings link had too small a font and poor contrast.

Finally, a tech-savvy user found that tabs on Finn were not properly coded for keyboard navigation, posing challenges for non-mouse and screen reader users.

2) Understandable and Operable.

We examined how easily users could understand and use the banners. Many faced barriers related to design and functionality. Almost all were overwhelmed by the amount of text and choices. One participant said the banner "stands in the way" of their goal, highlighting the need to minimize interaction time. Most users focused on button text, occasionally headings, and rarely read longer explanations. Long texts were overwhelming ("too much text, almost got seasick"), especially for the braille display user.

Nearly all participants struggled with jargon and vague terms. While "cookies" was acceptable, terms like "ad partners," "purposes," "suppliers," "recommended," and even "all" caused confusion. Participants recommended clearer language, formulated from a user perspective, rather than a technology-centered one—e.g., “necessary for login” instead of just “necessary.”

Visually impaired and older users favored banners that start with brief content and link to more details for “those who want to find out more.” Most preferred the banners over separate consent pages. Tabs and accordion menus (e.g., Finn) were helpful when used carefully, as they could otherwise hinder overview.

All participants found the “Reject all” button, even when hidden behind “Customize.” However, many noted the banner disappeared without feedback. A short confirmation message was recommended.

Some sites redirected users to different parts of the banner after clicking “Customize”—within the same banner (Finn), a new one (Skatteetaten, Facebook), or a separate page (Bufdir). Most preferred everything in one place, as on Finn. However, Finn solves this by reloading the page, which disrupts screen reader users who lose context and must navigate back.

3) Observations Not Related to Accessibility.

We evaluated whether users could revisit cookie banners after closing them, with mixed results. This was not possible on Skatteetaten. Many, especially older users, were unaware of this option but found it helpful once demonstrated.

Although several participants found footer links acceptable (“that is where it is usually located”), three, including older users, struggled with Finn’s auto-scroll, which prevented access to the page bottom.

There was confusion regarding the terms “Cookie,” “Privacy declaration,” and “Cookie settings” (Finn, Bufdir). The first two provided information about cookie use, while the latter required user interaction. A button labeled “Open cookie settings” could improve clarity.

Two cognitive challenges were identified in changing decisions. First, Facebook’s placement of the link at the bottom of an unstructured list required users to search through all links. A column layout, as suggested by one participant, could improve usability. Second, locating cookie settings in Facebook’s Privacy Center was demanding.

We also identified several issues that, while not directly related to accessibility, may violate privacy regulations: (1) Cookie settings could not be changed after a choice was made. (2) In practice, the user is required to make a choice regarding cookies to be able to read about their details. (3) Websites informed users about non-optional cookies even when not necessary. (4) Users were not informed that the website could be used without accepting optional cookies. (5) When revisiting settings, users could not retain previous choices without making a new selection.

B. Survey

Here, we present selected results from our report [18]. Detailed results can be found in our Github repository [19].

There were 151 respondents to the survey in total, consisting of 58% women, 39% men, and 3% non-binary individuals. The age distribution was as follows: 3% were 19-30 years old, 25% were 31-49, 23% were 50-65, and 48% were 66 or older. Most respondents used the internet multiple times a day (74%) or daily (24%), and only 2% used it weekly. 74% indicated no disabilities, 24% reported having an disability (or multiple), and 2% preferred not to disclose this information. Among those with disabilities, there were the categories cognition (14 respondents), vision (14, split equally between low vision and blindness), motor (7), mobility (6), hearing (3), and unspecified (1). The following survey results are categorized by themes.

1) Cookie Choice Preferences.

Users’ cookie choice preferences were similar between respondents with and without disabilities (cf. Figure 1). Among respondents with disabilities, 50% typically reject cookies, 25% accept without reading the banner information, 19% customize the settings, and 6% ignore cookies altogether. Among respondents without disabilities, the corresponding numbers are 48%, 29%, 21%, and 3%.

2) Perceived General Difficulty.

The perceived difficulty with cookie banners varied among individuals with and without disabilities (cf. Figure 2). Among respondents with disabilities, 50% found cookie banners more difficult than easy to handle (28% found it very and 22% quite difficult), 36% found it neither easy nor difficult, and 14% found it more easy than difficult (6% found it very easy and 8% quite easy). The corresponding numbers for respondents without disabilities are, 41%, (12% very difficult, 29% quite difficult), 36%, and 23% (7% very easy, 16% quite easy).

3) Perceived Readability.

The answers for perceived readability of text in cookie banners revealed differences between user with and users without disabilities (cf. Figure 3). Among those with disabilities, 55% found the text more difficult than easy (19% very and 36% quite difficult), 25% found it neither easy nor difficult, and 17% found it more easy than difficult (11% very easy, 6% quite easy). The corresponding numbers for respondents without disabilities are 44% (13% very and 31% quite difficult), 37%, and 18% (8% very easy, 10% quite easy).

4) Perceived Difficulty in Decision-Making.

Perceived difficulty in decision-making in cookie banners differed quite a bit between individuals with and without disabilities, too (cf. Figure 4). Among those with disabilities, 64% found making decisions more difficult than easy (22% very and 42% quite difficult), 8% found it neither easy nor difficult, and 27% found it more easy than difficult (19% very easy, 8% quite easy). The corresponding numbers for those without disabilities are 44% (10% very and 34% quite difficult), 25%, and 31% (16% very easy, 15% quite easy). Subsequently, we detail results from plain-text fields in the survey.

5) Feedback on Challenges with Cookies.

Out of 151 participants, 107 provided comments on the challenges they encounter with cookie banners.

Generally, users would rather not deal with cookies at all, aiming to bypass cookie banners as swiftly as possible. Many users find cookie banners confusing, bothersome, and time-consuming. Additionally, there are significant challenges tied to the lack of a universally accessible design for cookies. This is particularly problematic for individuals with disabilities and older adults. Some cookie banners are incompatible with assistive devices. Furthermore, too much text often leads to a cognitive overload for many users. Users reported challenges that can be categorized into four categories: lack of accessibility, lack of clarity, information overload, and manipulation.

Accessibility-related challenges are challenges that hinder their ability to make informed cookie choices:

- Inconsistent interface: The variation in the appearance and location of options causes confusion, making it difficult to locate “Accept only necessary” or “Reject all.”
- Inaccessible or unclear interfaces: When buttons are not compatible with assistive technologies or the text is hard to understand, users—especially those with disabilities—struggle to give informed consent.
- Challenges for older adults: Cookie banners are particularly challenging for elderly users, who may find them confusing as they generally struggle to navigate the web.
- Poor mobile adaptation: On mobile devices, cookie banners often cover large portions of the screen, making interaction difficult.
- Small font sizes: Tiny text makes it hard to read and understand cookie information, especially when large amounts of content are presented.
- Vanishing banners: Some banners disappear too quickly, preventing users from responding in time and causing frustration or confusion.

Lack of clarity refers to uncertainties, confusions, or lack of understanding about the information content and the choices presented in the cookie banner, and how they are explained, if at all:

- Unclear purpose: Users often do not understand exactly what cookies are or why they are used.
- Hidden or complex options: Choices, such as “Accept only necessary” are frequently buried behind multiple clicks or long lists.
- Unfamiliar terminology: Terms, such as “legitimate interests” or “necessary cookies” are unclear, leading to doubts about whether consent is genuinely respected.
- Uncertainty about consequences: Users are unsure what happens if they reject cookies, such as which site features may become unavailable.
- Confusion between functions: It is often unclear which settings relate to site functionality versus advertising.

Many users reported experiencing information overload and a feeling of being overwhelmed by the volume, complexity, and presentation of cookie content and choices:

- Complex and time-consuming: Cookie banners are often seen as unnecessarily complicated and tedious to navigate — more annoying than difficult.
- Cumbersome rejection: Users were frustrated by having to tick or untick many boxes and noted that some websites deliberately hide rejection options.
- Too many choices: Users felt overwhelmed by the number of decisions and the volume of information they had to process.
- Excessive text: Long, legalistic language discourages reading and understanding.
- Loss of focus: Cookie prompts disrupt attention and make it harder to engage with the website.

Many users perceived manipulation in the design and behavior of cookie banners, which was seen as pressuring them into choices they would not otherwise prefer, or that may not be in their best interest:

- Manipulative design: Many feel the design encourages cookie acceptance by highlighting “accept all” buttons through color or placement.
- Forced acceptance: Users feel compelled to accept cookies to access the site, frustrated by the difficulty of rejecting or selecting only necessary cookies.
- Lack of control: Users report feeling a loss of control over their data, with some finding it unsettling to accept all cookies and choosing to leave the site. Concerns include what data is collected and why.
- Cookies as surveillance: Some view cookies as spying tools, worried about unclear data collection of personal and geographic data, and potential third-party misuse.

6) Feedback on Improvement Suggestions for Cookies.

109 respondents proposed several solutions for simplifying interaction with cookie banners:

- Standardization: Establish a standard structure for all cookie banners.
- Have “Reject all” or “Only necessary” as default: Make it easier to reject all cookies and proposed making this option more prominent. Ideally, pressing “Enter” should reject all cookies or accept only those necessary.
- Simplified interface: Offer a straightforward choice between accepting or rejecting all cookies, with an option to delve into more specific settings if needed.
- Browser preset preferences across sites: Allow for cookie settings to be saved in the browser so the same preferences apply across all websites.
- Clear, Concise Text: Use simple and understandable text that quickly explains the implications of each choice, complemented by large buttons with sufficient contrast. It was suggested that language be simplified, and explanations be provided for each cookie setting.
- Better placement: Position the cookie banner in a way that does not obscure too much of the screen, especially on mobile devices.

V. Discussion

We present results from the user tests and the survey separately, followed by a section with recommendations based on our discussion.

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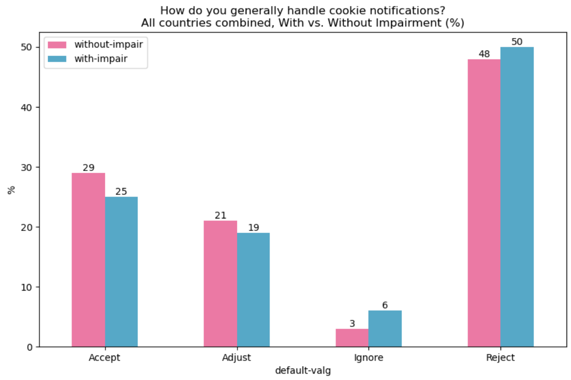

Figure 1. Cookie choice preferences (people with vs. without disabilities).

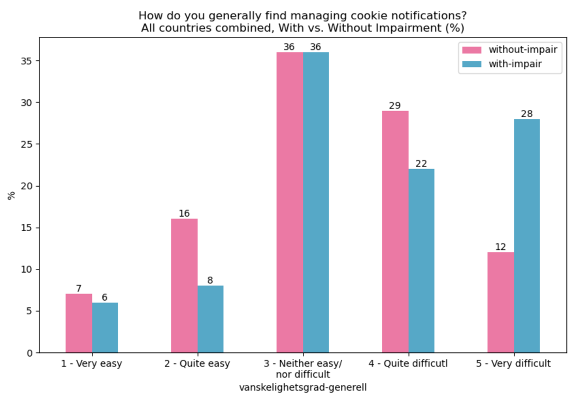

Figure 2. Perceived general difficulty (people with vs. without disabilities).

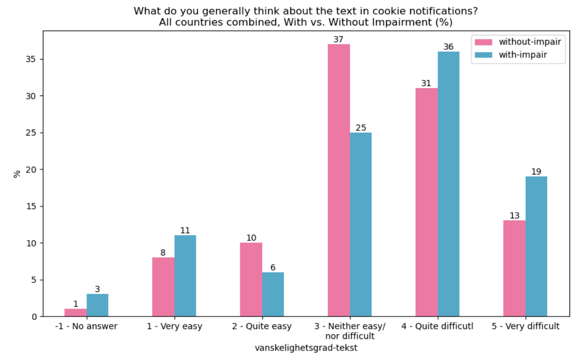

Figure 3. Perceived readability (people with vs. without disabilities).

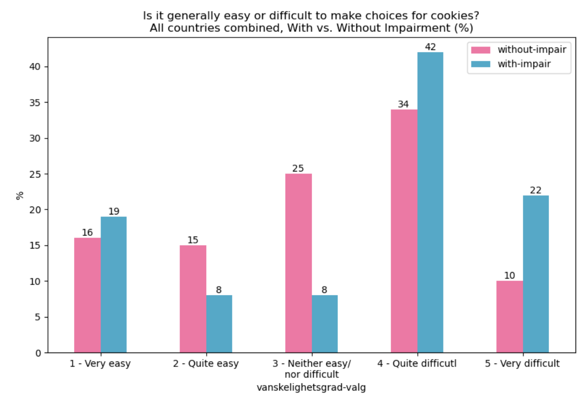

Figure 4. Perceived difficulty in decision-making (people with vs. without disabilities)

A. *User Test-Related Results*

The participant count (12) was limited by budget, making the sample non-representative, though we aimed for diversity in gender, age, abilities, and conditions.

An interesting finding was that there are common needs and desires across multiple functional groups. Users expected the banner to be located in the same place "as always/usual" to quickly move forward and avoid having to search around. For screen reader users and users with limited range and manipulation ability, navigating to and within cookie banners by means of tabbing was difficult. For people with low technical skills, limited cognition, language skills, or learning abilities, searching was stressful and consumed patience and energy.

Another interesting result was that some screen readers simply ignored blocking cookie banners and let the user proceed to the page, withholding them their choices and ignoring current legal regulations. In these cases, screen reader users are disadvantaged in comparison to others.

Ensuring that text is not excessively long or complicated was important for all participants. Screen reader users struggled to locate the banner's starting point due to difficulties in getting an overview of the text. For people with limited cognition, language, or learning, reading through long texts was challenging as well. All groups had problems understanding non-standard terms (jargon).

Visual indicators for buttons (primary or secondary) appear not to work well for most users. Such indicators are not detected by screen readers and likely not sufficiently understood by people with limited cognition, or learning abilities, or with low technical interest.

B. *Survey-Related Results*

Most users tend to reject cookies by default, likely due to the complexity of the topic and limited understanding of how cookies work. Simple design and concise and comprehensive explanations are therefore essential. Few users customize settings, possibly because the process is too intricate, complex, or time-consuming.

Users with disabilities generally find cookie banners harder to manage, likely due to poor accessibility, excessive text, or confusing navigation. In both groups, more users found cookie management challenging than easy, especially among those with disabilities.

Text readability is a common issue, particularly for users with disabilities—over half reported difficulty reading / understanding the content. Even among users without disabilities, many found the text more challenging than easy, suggesting that descriptions and explanations are lengthy and not composed in a clear, simple manner.

Regarding limitations of our approach, our sample was not controlled, as participants were recruited through interest organizations and online forums. Despite this, our work offers valuable insights into how people with disabilities experience cookie banners. We also believe that the blend of quantitative and qualitative data offers a more profound understanding of the issues and potential solutions.

C. Recommendations

The recommendations are based on the findings in the user tests and the textual feedback from the survey.

Both the English term "cookie" and the Norwegian equivalent "informasjonskapsler" can be used. However, this must be done in a consistent manner. (This recommendation should be tested for other countries.)

There should be a standardized layout for the cookie banner, consistent across websites in terms of option range, text, and presentation. This layout should include easily accessible options which minimally contain three options: “Reject optional,” “Accept all,” and “Customize / Settings / Choose yourself.” A brief explanation should be provided for what “optional” entails.

The choices should be easy to understand and presented in a neutral manner:

- “Reject” should have the same prominence as “Accept.” Both buttons should be located side by side. “Reject” should be placed first.
- Items that cannot be opted out from should not resemble those that can be changed, regardless of whether they are disabled or not.
- There should be standardized explanations and a presentation form so that the user can easily understand and navigate. This could be standardized across multiple website owners or by international organizations like W3C or EU.
- Settings for individual cookie selection should be available for those who might want to use them.

There should be consistent confirmation messages after performed actions, and the user should be informed about how to make changes:

- After pressing “Reject” or “Accept,” a confirmation should replace the banner content, preferably with a “Close” button. This confirmation could also include where the link to the cookie settings is located if one wishes to change their mind later.
- After pressing “Customize,” the banner content could be replaced with the “Customize”-banner, displaying checkboxes above and below the “Save” buttons. If there are many boxes, consider using tabs, accordion menus, etc., as well as “Check all” and “Remove all checkmarks” buttons.

The presentation of information and operational elements should be simple, clear, and concise:

- Overuse of text should be avoided. It could however be beneficial to link to a privacy policy where cookies are explained in further detail.
- Explanatory text should be concise and comprehensive. Jargon and uncommon words should be avoided or explained.
- Consistent language should be used both within a website. It should be explained what the options mean and what choosing them entails. In particular, the term “Necessary cookies / Legitimate interest” should be explained in terms of why they are necessary, and which cookies this applies to.
- Proper structuring of the content is recommended to avoid too many alternatives at once during decision-making. This refers particularly to design measures which support content hierarchies, such as accordions, content hiding, links to further information, and similar.

Common recommendations for good accessibility and usability should be followed, for example WCAG. For instance, appropriate contrast should be utilized in the banner. Ideally, large font should be used for better usability or font size should be adjustable. Buttons should be prominently displayed and clear on the website with high contrasts as well.

If the cookie banner is displayed as an overlay dialog, the HTML dialog element should preferably be used. If the HTML dialog is not used for the banner, the banner should be prominently displayed at the top of the page, or the website should have a shortcut to it at the top of the page.

A link to the settings should also be placed at the bottom (footer) of the page for easy later access.

In cases where the user has already made a choice and wishes to see the settings again, the banner should include an option that allows the user to retain their current settings and close the banner.

Consideration should be given to potential conflicts between the cookie banner and other pop-up dialogs on the site, such as shopping cart, newsletter subscriptions, user surveys, etc. A possible solution could be to ensure that these banners do not appear simultaneously to avoid user confusion and distraction.

We have summarized these recommendations in guidelines found in Appendix 1 and created example prototypes based on them in Appendix 2.

VI. Conclusion and Future Work

In this study, we developed recommendations and guidelines for more universally designed cookie banners on websites based on the results from user evaluations and a survey. The focus of our work was on the universal design of cookie banners with special attention to user perceptions, both with and without disabilities.

Generally, users experience challenges with cookie banners due to a lack of digital accessibility, lack of clarity, information overload, and manipulative design. The participants in this study suggested several improvements. These include standardization of language use in cookie banners for more transparent choices, simple and prominently placed interfaces, cross-site cookie preferences in the browser, and brevity and clarity of text.

The user tests and survey further underscored that cookie banners are generally perceived as a barrier to achieving a goal on a website. We identified several cognitive and sensory challenges, such as excessive text, use of jargon, complex navigation, and issues with color choices and overall accessibility. This poses challenges for users with disabilities, who reported a range of problems, including incompatibility with assistive tools like screen readers.

The project significantly contributes to previous research by specifically focusing on the needs of people with disabilities in the universal design cookie banners. Universal design deficiencies may prevent these users from accessing a website, obtaining needed information, or choosing their preferred option to provide informed consent, which in turn constitutes a violation of their right for privacy.

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Appendix 1: Checklist for universally designed cookie banners

This checklist helps website owners make cookie banners accessible to all users, including those with disabilities. It offers practical tips on design, clarity, navigation, and technical accessibility to support informed choices across devices and assistive tools—while also meeting legal standards and improving user experience.

A. Design and visibility

Ensure that the cookie banner is immediately visible upon the first visit to the website. It should be easy to find and not be hidden or difficult to access.

- Ensure that the cookie banner is at the beginning of the reading order.
- Keep the banner simple and focused, without too much text.
- Use a clear and large design that stands out so that users can quickly understand the purpose and what is expected.
- If the cookie banner is placed on a smaller screen, ensure that it takes up enough space to make it easy to interact with.

B. User-friendly options

Provide three clear and simple options for users:

- "Reject optional cookies": An option that allows users to choose to only accept necessary cookies and reject optional ones. A brief explanation should be provided for what "optional" entails.
- "Accept all cookies": A choice that makes it easy to quickly accept all cookies.
- "Customize yourself": An option that gives the user full control over cookie settings and lets them choose exactly which cookies they want to accept.

Ensure that each option is clear and easy to understand so that users can quickly make an informed decision.

C. Clarity and transparency

Be clear about what the different cookie options mean for the user and what they can expect from the website's functionality depending on what they choose.

If the cookie contains longer texts with more detailed information about how you or your partners use data, you can put this in collapsible paragraphs or as links, so that the user can choose how much information they want to see.

D. Understandability

Use easy-to-understand terms instead of technical terms to make it easy for all users to make an informed decision.

Where possible, insert links to explanations of words and terms used.

E. Easy navigation

Give users the ability to quickly and easily reject or accept all cookies with a single click, without having to go through multiple steps.

Ensure there is a clear and easily accessible link for users who want to change their choices or get more information about cookies and their purpose.

F. Technical accessibility

Ensure that the cookie banner works well on both desktop and mobile devices.

Ensure that the cookie banner is accessible to users with different types of assistive tools.

Check that the cookie banner complies with relevant accessibility standards [8, p. 301], [17].

G. User-friendly settings

Provide a simple and intuitive method that allows users to change cookie settings at any time after they have made an initial choice.

Ensure users do not need to search long to find out where they can change their settings. Provide a clear link or button to return to cookie choices.

APPENDIX 2: CHECKLIST FOR UNIVERSALLY DESIGNE COOKIE BANNERS

The prototype (cf. Figure 5) is based on the recommendations in this article. Some of the key recommendations illustrated in the prototype are:

- Cookie banners should not cover the screen.
- The banner should be placed centrally on the screen so that it is easy to find.
- There should be a clear sender.
- There are explanations for unusual terms used.
- There is a heading.
- The banner does not contain too much information.
- Extra information can be obtained by unfolding elements.
- The banner contains three choices that clearly distinguish from each other.

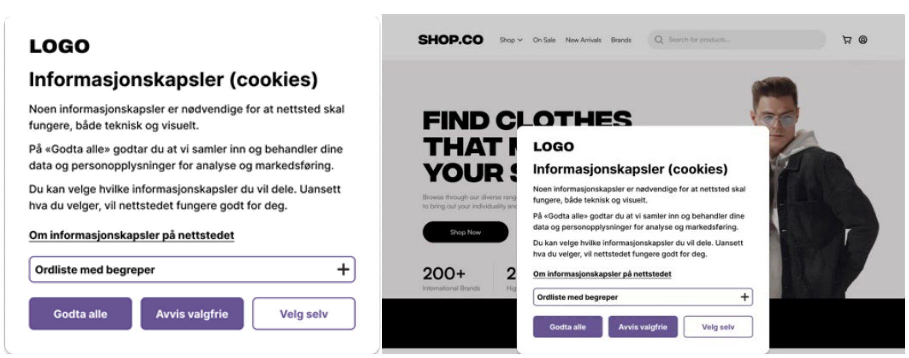

Figure 5. Prototypes of accessible cookie banners based on recommendations described in this article

Identification of Design Recommendations for Augmented Reality Authors in Corporate Training

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***Abstract*—Innovative technologies, such as Augmented Reality (AR), introduce new interaction paradigms, demanding the identification of software requirements during the software development process. In general, design recommendations are related to this, supporting the design of applications positively and meeting stakeholder needs. However, current research lacks context-specific AR design recommendations. This study addresses this gap by identifying and analyzing practical AR design recommendations relevant to the evaluation phase of the User-Centered Design (UCD) process. We rely on an existing dataset of Mixed Reality (MR) design recommendations. We applied a multi-method approach by (1) extending the dataset with AR-specific recommendations published since 2020, (2) classifying the identified recommendations using a NLP classification approach based on a pre-trained Sentence Transformer model, (3) summarizing the content of all topics, and (4) evaluating their relevance concerning AR in Corporate Training (CT) both based on a qualitative Round Robin approach with five experts. As a result, an updated dataset of 597 practitioner design recommendations, classified into 84 topics, is provided with new insights into their applicability in the context of AR in CT. Based on this, 32 topics with a total of 284 statements were evaluated as relevant for AR in CT. This research directly contributes to the authors' work for extending their AR-specific User Experience (UX) measurement approach, supporting AR authors in targeting the improvement of AR applications for CT scenarios.**

Keywords-Augmented Reality (AR); Software Requirements Engineering; AR Design Recommendations; Corporate Training (CT); Natural Language Processing (NLP); Semantic Textual Similarity (STS); Sentence Transformers (SBERT).

I. INTRODUCTION

Innovative technologies, such as Augmented Reality (AR), create new interaction paradigms. It is essential to identify the application's requirements for developing and designing the respective features. AR authoring refers to the process of creating an AR application through various development steps [1]. In this context, we want to specify the different roles of people in relation to AR authoring, following the differentiation by [1]. In our understanding, AR authors focus on the creation of animations, 3D models, visualizations, and interactive elements (e.g., shadows, textures, color schemes, or sound design) by using authoring tools.

AR authoring can be broadly classified into the interdisciplinary field of software engineering, describing the process of developing software systems [2]. Software requirements elicitation as part of software requirements engineering is the initial step in development, collecting, analyzing, and understanding the relevant requirements and needs of stakeholders [3]–[6].

Previous research analyzed the activities related to the requirements elicitation process [7]–[10] and the effectiveness of requirements elicitation techniques [11]–[14]. Different techniques can be found in the literature. Among the traditional methods, interviews, scenarios, and questionnaires are most commonly applied. For a detailed overview, see [6].

According to [15], requirements are the basis for system design and development. However, not all requirements must be determined for each new application or technology. Using a technology for some time in a certain application domain results in design practices and lessons learned over time, which in turn can be recorded in respective design principles, guidelines, heuristics, or recommendations. These provide an orientation in the form of standards and best practices for system design and development, playing a crucial role in efficiently designing usable interactive technologies in an early stage [16]–[19].

However, applying general recommendations or recommendations from other contexts risks neglecting the new interaction paradigms [18]. Thus, context-specific recommendations are essential for developing and designing new technologies. Current research states a lack of relevant, practical, and applicable design recommendations for AR [1][20], and especially for Corporate Training (CT).

In this article, we aim to identify relevant AR design recommendations for CT, resulting in an updated dataset for AR authors. The study is based on an existing dataset with classified Mixed Reality (MR) design recommendations by [18]. We apply a multi-method approach by enhancing and updating the existing dataset, summarizing the main content of subtopics, and evaluating the relevance of subtopics concerning our research objective. Against this background, we address the following research questions:

- ***RQ1:*** *What practical AR-specific design recommendations have been proposed since 2020?*
- ***RQ2:*** *How can the newly identified AR design recommendations be classified?*
- ***RQ3:*** *How can the resulting topics be described and communicated?*
- ***RQ4:*** *Which topics are relevant for AR authors to improve AR applications in CT?*

Based on this, we want to make a further classification of this work, as this has specific relevance for the author's doctoral thesis. Our previous research focused on the User

Experience (UX) evaluation of AR applications in CT. The study results are used to further extend the AR-specific UX measurement approach **UXARcis** [21]. Regarding the User-Centered Design (UCD) process, the research is located in the evaluation phase within the UCD process [22]. Figure 1 shows the UCD process.

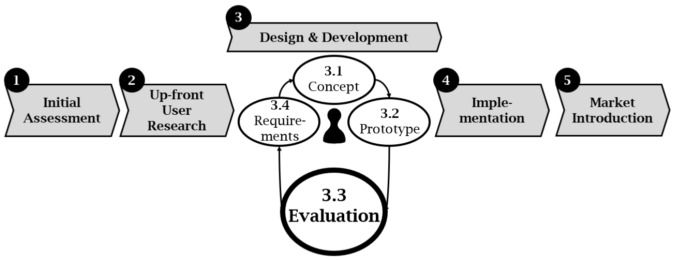

Figure 1. User-Centered Design (UCD) process based on [22]

This means that an AR application no longer has to be developed from scratch, but a functioning AR prototype already exists. In this context, AR authors design the corresponding application features. This focus was considered in the methodological approach of this paper.

The article is structured as follows: Section II introduces the related work to establish a common understanding. Section III explains the multi-method approach of this study, followed by the results in Section IV. A Conclusion is given in Section V, including a Discussion in Section V-A and Limitations in Section V-B. Lastly, our future research is explained in Section VI.

II. Augmented Reality Design Recommendations

This Section II introduces the related work for this study. We want to clarify terms and definitions in advance to establish a common understanding. Over the last decades, different terms such as *principle*, *guideline*, or *heuristics* have been established [18][23]. Principles are formulated in general terms [15][24]. Guidelines, on the other hand, are more specific [18]. They can be translated into heuristics, which can be used to evaluate systems [25]. Fu et al. consolidated the following descriptions [23]:

- ***Principle***: A fundamental rule or law, derived inductively from extensive experience and/or empirical evidence, which provides design process guidance to increase the chance of reaching a successful solution
- ***Guideline***: A context-dependent directive, based on extensive experience and/or empirical evidence, which provides design process direction to increase the chance of reaching a successful solution.
- ***Heuristics***: A context-dependent directive, based on intuition, tacit knowledge, or experiential understanding, which provides design process direction to increase the chance of reaching a satisfactory but not necessarily optimal solution.

We will further apply the term ***recommendations***, including all three terms, to establish a common understanding for this article.

Context-specific design recommendations are essential as the presentation and interaction of AR differ from other media technologies. Previous research has already worked on this topic, identifying various design recommendations. We mainly refer to the work by [18]. Krauß et al. conducted an extensive literature review, analyzing and summarizing existing approaches, including design recommendations from science and practice up to 2020. In summary, 875 design recommendations for MR applications based on 89 scientific papers and documentation from six industry companies were analyzed. A basic distinction was made between *Scientific Design Recommendations (SDRs)* and *Practitioner Design Recommendations (PDRs)*. This is relevant because, in addition to scientific articles and findings, there are practical recommendations from companies developing the hardware and software concerning AR. The respective statements in both clusters were further analyzed and classified into different main topics, subtopics, and relation to the respective device characteristics (handheld or head-mounted). For details regarding the classification, we refer to [18].

Based on the results, [18] showed that research often adapts traditional (non-spatial) UI principles, such as Nielsen's heuristics [26], without sufficiently addressing MR-specific issues, like ergonomics, spatial interaction, and environment. In contrast, practical recommendations from the industry focus more on MR-specific and practical concerns. Furthermore, SDRs are highly abstract and generic concerning device specification and development, often lacking concrete examples. PDRs are much more detailed, practical, and illustrated with examples to guide application development [18].

To have a positive effect, design recommendations must be seen as essential and valid advice by development teams. But this is often not the case in practice. Design recommendations can be considered as irrelevant and thus be ignored [20] due to the following reasons: Problem of communication, abstraction, research-induced bias [27], ambiguous wording, addressing different target groups with different types of information, and the medium of publication [18].

Based on this, [18] stated relevant implications. Existing design recommendations should be investigated and validated, focusing on the context-specific use of technology. This includes being explicit about the target group, context, and application goals. This should, in turn, be based on transparent, high-quality data and shared practices. Moreover, it is essential to distinguish between research-driven recommendations aimed at enhancing theory (divergent) and practice-driven recommendations supporting system development (convergent) [28]. Existing recommendations should be further structured and classified to facilitate access and better communication channels for practitioners and researchers [18].

Since 2020, little research has been conducted on AR design recommendations. Most papers adopt existing recommendations and apply them to a specific use case. Three articles were found adopting existing recommendations to the area of corporate training (see [29]–[32]).

Agati et al. [29] analyzed existing AR design recommendations for designing AR applications in manual assembly and classified the identified recommendations into the four groups *usability*, *cognitive*, *ergonomics*, and *corporate-related* based on their similarity. Haegle et al. [30] present a set of design recommendations concerning AR assistance in manufacturing. The authors mapped existing recommendations from the literature to the identified challenges in the field of manufacturing machinery.

Only two articles could be identified proposing new recommendations. Chen et al. [32] used public online videos as a basis to identify design patterns, from which they derived new design recommendations for AR-based assembly instructions. Jeffri and Rambli [31] examined the existing types of visual features implemented in AR applications for manual assembly. Based on these, the authors present interface recommendations.

Besides these, no further relevant approaches regarding AR design recommendations were conducted. Our study approach, based on [18], is explained below.

III. Methodological Approach

We applied a multi-method approach containing the four research steps in relation to the research questions:

1) **Identification of new AR design recommendations** based on a Review.
2) **Semantic topic classification of new AR design recommendations** based on an NLP approach.
3) **Content summarization of AR design recommendations topic** based on a qualitative Round Robin approach with AR authors.
4) **Evaluation of relevant topics concerning AR in CT** by AR authors.

The current state of existing design recommendations for MR applications, as presented in [18], provides the basis for this study. We focus on the PDRs, as the SDRs are mostly too generic and, thus, not useful for our research objective [18]. The PDR dataset contains 504 statements, classified into 13 main topics and 84 respective subtopics. Krauß et al. [18] provided their dataset for our research. In the following, we focus on the subtopics as the main topics are too broad. For simplicity, we will only use the term ***topic*** instead of subtopic in the following. This relates to the subtopics by [18]. An example topic is shown in the Appendix A.

In the first step, we identified new practical AR design recommendations developed since 2020, enhancing the initial dataset of [18] regarding our research objective. The initial dataset by [18] referred to MR and, therefore, also covers other types such as VR based on the reality-virtuality continuum by [33]. In the context of this study, we exclusively focus on AR in relation to the research objective. For this, we followed the approach by [18], analyzing market-leading AR-related companies, including Apple [34], Google [35], Microsoft [36], Magic Leap [37], IBM, and Spark AR [38]. We examined the respective developer documentation containing the design recommendations. However, the developer documentation covering many aspects of development is usually very extensive. The relevant practical design recommendations are typically listed as *best practices*. Hence, we focus our search on the respective statements in relation to *best practices*. Moreover, only design recommendations relevant to AR authors in the respective phase of UCD (see I) were included. Lastly, we also identified practical AR design recommendations from the Nielsen & Norman group during our search [39]. Due to the popularity of the Nielsen heuristics and their inclusion in the SDR by [18], we also considered these. To sum up, we focused on AR-specific statements for best practices within the developer documentation of the market-leading AR-related companies proposed since 2020.

In the second step, we used natural language processing (NLP) to analyze Semantic Textual Similarity (STS) as a common approach for text classification [40], aiming to align the identified statements with existing topics semantically. To achieve this, we applied a pre-trained Sentence Transformer model (SBERT) to analyze STS between each identified statement and the existing topics and their classified statements. This technique enables a fine-grained semantic comparison by transforming textual inputs into dense vector embeddings [41]–[45].

The SBERT is based on the BERT network. BERT is a pre-trained transformer network [46], setting a new benchmark for various NLP tasks [47], indicating the best results for text similarity tasks [48]. The SBERT by [45] enhances the original BERT model using siamese and triplet networks. This enables the application of the SBERT on common STS tasks, such as clustering or text classification [45]. Moreover, previous research showed high potential of applying NLP techniques in UX research activities [49]–[51].

For our analysis, we used the ***all-mpnet-base-v2*** model demonstrating strong performance across various STS tasks. By computing the cosine similarity between the embeddings of each newly identified statement and those representing the existing topics, we could classify the new data points according to their highest semantic proximity. This vector-based comparison facilitates an accurate assignment of semantically similar content, as discussed in prior work by [45][49]. We used the Python module *sentence transformer library*, including the SBERT for operations [45]. We provided the code as a public repository in git for details, transparency, and comprehensibility (see [52]).

We note that LLMs drive the development and state of the art in NLP tasks. However, small models, such as BERT or SBERT, show sufficient performance for our approach in terms of our dataset and objective [53].

Based on the actualized data set, we applied a Round Robin evaluation approach [54] using five domain experts concerning this topic to summarize and evaluate all 84 topics. Concerning [55], five domain experts are a sufficient number of participants for an evaluation. In particular, three experts work as research associates at a university with more than three years of experience researching, developing, and designing AR applications. The fourth expert has worked as a research assistant at a university, gaining experience with AR authoring and heuristics, and is now a senior consultant in UX design and software requirements engineering. The last author is both a research assistant at the Fraunhofer Institute for Computer Graphics Research IGD and self-employed, researching and working on AR and VR with a practical focus. This specific selection of domain experts ensures that all relevant topics of this research regarding AR authoring, UX design, and software requirements are covered. Moreover, both the research and practice perspective is included.

All topics and their included statements were split equally into five lists, each containing 17 topics and respective statements (one list with 16 topics). The numbers (n - n) within Figure 2 represent the topics within each list. The approach followed a five-round evaluation format. In each round, the experts had the task of analyzing all statements within the 17 topics per list and summarizing the relevant content. The lists with the summaries were then passed on to the next expert, who reviewed and extended the previous expert's input. This iterative process was repeated five times, ensuring that every expert contributed to all 84 topics and all five lists. As a result, each author has completed the required task for all topics. The approach is illustrated in Figure 2:

	Expert (1)	Expert (2)	Expert (3)	Expert (4)	Expert (5)
Round (1)	1-17	18 - 34	35 - 51	52 - 68	69 - 84
Round (2)	18 - 34	35 - 51	52 - 68	69 - 84	1-17
Round (3)	35 - 51	52 - 68	69 - 84	1-17	18 - 34
Round (4)	52 - 68	69 - 84	1-17	18 - 34	35 - 51
Round (5)	69 - 84	1-17	18 - 34	35 - 51	52 - 68

Figure 2. Round Robin Evaluation Approach.

Afterwards, all experts evaluated the relevance of each topic for the use of AR in Corporate Training (CT), specifically in the context of the evaluation phase of the UCD process, where a functional AR prototype already exists. This was done because some topics, e.g., hardware and software compatibility, may be irrelevant, as they pertain more to early development rather than to the refinement of working prototypes.

IV. Study Results

Section IV provides the results concerning the four methodological steps. In Section IV-A, we indicate the identified AR design recommendations developed since 2020, followed by their subtopic classification based on the STS in Section IV-B. In Section IV-C, we exemplarily illustrate the subtopic summarization. Lastly, we present the relevant subtopics for AR in CT in Section IV-D. Please note that not all results can be presented in detail due to paper restrictions. We refer to the authors' additional resources for detailed insights (see [52]).

A. Identification AR Design Guidelines

In summary, we elicited 93 new design recommendations specifically referring to AR. In particular, 10 statements were proposed by Nielsen & Norman group [39], whereas Magic Leap provided 83 statements [37]. In particular, Magic Leap proposed five categories regarding best practices for AR. However, three of them do not apply to our research objective because they are too technical or not relevant to the phase of the UCD process. Thus, two categories with 83 statements relevant for AR authors were applied (*Audio Guideline* and *Comfort and Content Placement*) [37].

Google [35], Apple [34], and Microsoft [36] did not publish any further or updated existing guidelines. IBM is not available anymore. This also applies to meta, as meta spark was shut down at the beginning of 2025 [38]. This results in a total of 597 practioner design recommendations *(as of: April 2025)*.

B. Classification of AR Design Recommendations

The 93 identified statements were classified into 26 topics, grouped under nine main categories. The cosine similarity values range between 0.26 and 0.69. The detailed classification is illustrated in Table I. No fixed cosine similarity threshold was applied, as there is no universally accepted cut-off value that defines semantic similarity in sentence embeddings. Instead, each statement was assigned to the topic with the highest similarity score compared to all other clusters. This ensures that every statement is classified based on its relative semantic proximity, aligning with established practices in clustering and semantic similarity analysis.

Most topics were assigned one, two, or three statements, whereas more statements were assigned to the topics *Audio Feedback* (n = 8), *Audio* (n = 25), and *Content Placement* (n = 9). This is consistent with the description by [37], as the main categories are defined as *Audio Guidelines* and *Comfort and Content Placement*, from which the identified statements are taken.

C. Summarization of Topics Content and Meaning

All topics and respective statements were analyzed, and their content was summarized. In the following, we include the resulting summarization of our exemplary topic (see III). For the comprehensive data, including all descriptions, we refer to our research report [56].

> ***Topic**: Consistency*
> ***Topic summarization**: This topic is about making your app feel familiar, safe, and easy to use. It includes using standard icons, common interaction patterns, and consistent visuals so users know what to expect. Avoid making people learn new ways to do simple things when familiar ones work just fine.*

TABLE I. STATEMENT CLASSIFICATION BASED ON STS EVALUATION RESULTS.

Main topic	Topic	Statements	Cosine value
Guidance	Instructions	1	0.41
Input Modalities	Fitt's Law for Touch Interaction	1	0.29
Interactivity	Object Placement	1	0.50
Interactivity	Animations	2	0.38; 0.47
Interactivity	Content SpawnMmechanic	1	0.45
Controls	Control Placement in Screen Space	1	0.35
Multi-User Experience	Shared spaces	2	0.33; 0.38
Design Principles	Customization	2	0.43; 0.47
Design Principles	Law of Practice	3	0.34 - 0.43
Design Principles	Inform about Waiting Time	1	0.48
Design Principles	Information revealing	1	0.43
Design Principles	Accessibility (visuals)	1	0.37
Design Principles	Ergonomics (avoid muscle fatigue)	2	0.42; 0.51
Design Principles	Ergonomics (avoid head & neck fatigue)	2	0.31; 0.33
Technical Requirements	System Architecture	1	0.49
Technical Requirements	Performance	1	0.26
Technical Requirements	Hardware Properties	1	0.30
Feedback	Haptic Feedback (phones)	1	0.52
Feedback	Audio Feedback	8	0.42 - 0.58
Feedback	Feedback	1	0.42
Feedback	Audio	25	0.26 - 0.60
Feedback	Notifications	3	0.40 - 0.46
Spatial Design	FOV	1	0.35
Spatial Design	Content Placement	9	0.28 - 0.46
Spatial Design	Headlocked Content	3	0.40 - 0.50
Spatial Design	Design spaces	1	0.41

D. Relevance of Topics regarding AR in CT

To select the relevant topics, we refer to [57]. The authors described and investigated the determination of the Content Validity Index (CVI) as a representative indicator of quality. They showed that, in a group of five experts, a CVI of at least ***0.78*** must be achieved to ensure content quality. For calculation, the number of experts who rated it as relevant is divided by the total number of experts. This means that at least four of the five experts (4/5 = 0.8) must classify the respective topic as relevant to reach the threshold [57]. Thus, we excluded all topics rated as relevant by three or fewer experts. This results in **32** topics, with a total of **284** statements. The topics are illustrated in the following. The full list, including the respective statements and summarizations, is provided in [52].

1) Appropriate interplay of virtual content and physical environments
2) Attention directors
3) Instructions
4) Onboarding
5) Hand & finger gestures
6) Textures - Visual Realism and Appearance of Objects
7) Occlusion
8) Image detection
9) Handling Interruptions / Relocalization
10) Surface Detection
11) Affordance
12) Visual cues for object manipulation
13) Object Placement
14) Object Manipulation
15) Encourage to explore
16) Keep the focus on AR experience, but use 2D-UI On-Screen elements when needed
17) Error prevention & recovery
18) Consider and show User's required Effort
19) Law of practice
20) Inform about Waiting Time
21) Text / Font
22) Accessibility (visuals)
23) Ergonomics (avoid muscle fatigue)
24) Ergonomics (avoid head & neck fatigue)
25) Pause / Breaks
26) Performance
27) Audio Feedback
28) Feedback
29) FOV
30) Content Placement
31) Headlocked content
32) Anchored UI

V. CONCLUSION

This article extends and specifies previous research on MR design recommendations by [18] regarding AR in CT. We applied a multi-method approach to update the dataset with existing design recommendations and further prepare it for our future research regarding AR in CT. In particular, we identified 93 new AR-specific design recommendations, classified into 26 topics, since 2020. We classified them using an NLP classification approach based on a pre-trained Sentence Transformer model, summarized the content of the topics, and evaluated their relevance to AR in CT using a qualitative Round Robin approach with AR authors. As a result, we provide an actualized dataset with AR design recommendations for AR authors relevant to CT. The dataset consists of statements classified into topics, along with a summary of the topic's content and meaning. In the following, we derive implications and limitations.

A. Discussion and Implications

All research questions could be answered. Based on the results, we derive relevant implications. AR is a rapidly evolving field, driven by continuous advancements in both hardware and software capabilities, frameworks, and interaction paradigms. As AR technologies mature and diversify, so do users' expectations, behaviors, and needs. This dynamic state affects the requirements for designing and developing such applications. Moreover, developers and designers gather valuable experience as more AR applications are implemented across different domains. This results in new insights, refined methods, and design lessons learned from practice over time. This study bridges the five-year time gap, providing an actualized dataset with AR-specific design recommendations proposed since 2020.

Furthermore, the actualized dataset of AR-specific design recommendations provides several practical implications for AR authors regarding applications in CT. First, the summarized topics and their associated statements serve as direct guidance during the design and implementation of AR applications. By integrating these recommendations, AR authors can proactively address known usability and interaction challenges. Second, the topics and respective statements provide a foundation for structured expert evaluations of existing AR applications. Similar to established methods such as heuristic evaluation or cognitive walkthroughs, the recommendations can be applied as a checklist to review functional prototypes or deployed applications [58]. This enables evaluators to systematically assess whether key design principles are met and generate targeted suggestions for improvement. Thus, the dataset not only supports initial design efforts but also fosters continuous quality assurance and iterative enhancement of AR experiences in practice.

B. Limitations

While we successfully answered all research questions, some limitations need to be addressed. We want to note that we only focused on the PDRs by the six market-leading AR-related companies, following the approach proposed by [18]. The majority of newly identified statements result from one company [37]. Both the literature on SDR and other practical guidelines, which are certainly helpful, were included. As another aspect, the SBERT is a pre-trained model based on a general training dataset. No ground truth data for training was applied. Moreover, some of the topics are very similar in meaning. Thus, the STS-based classification may be inaccurate.

Moreover, we want to bring up a critical aspect regarding our provided dataset. Both the updated dataset and the final list of design recommendations for AR in CT are complex to use, as they contain a large number of statements. From a practical perspective, it is almost impossible to work with it, either as a checklist or a basis for the review, nor during the design process. To use them effectively in practice, further steps must be taken. For instance, the topics and the respective statements can be assigned to specific system properties. This allows further classification and specification. We want to state that we are aware of this problem. This work provides the basis and preparation for future research to create useful material for AR authors.

VI. Outlook & Future Research

Previous research already stated that UX is shaped in the early design phase [59], [60]. However, simply applying design recommendations can lead to problems, as the use of design recommendations depends on the authors' experience [61]. Furthermore, when designing using design guidelines, the subjective opinions of the authors also play a role. They intend to create a certain experience. However, it cannot be ensured that users will actually perceive the intended experience in this way. This is a fundamental discrepancy already described in early UX research [62].

Therefore, without the use of user evaluations, it remains unclear whether the application is perceived as good or bad by the users. It is crucial to identify the application's deficiencies by involving users. However, it remains unclear which weaknesses can be improved by applying which design recommendations. No concrete connection between specific AR design recommendations and the relevant dimensions of user perception exists.

The result provides the basis for extending our previous research. We aim to combine the relevant AR design recommendation topics with the structure of our proposed AR-specific UX measurement approach **UXARcis** [21]. In particular, we want to examine the relationship between specific topics and the UXARcis measurement dimensions by classifying them. As a result, we aim to bridge the gap between empirical UX evaluation methods and their practical applicability for AR in CT, as this remains a major issue in UX research [63].

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APPENDIX

***Topic**: Consistency*
***Statements**:*

- *Be reliable. Use global, consistent interactions to make your app both easy to use and safe to explore.*
- *System icons provide users with immediately recognizable visual queues and information. You can use the following icons are available for use in your apps and experiences.*
- *Use consistent, clear, and meaningful symbols.*
- *Certain Control actions must be familiar, intuitive, and adhere to platform conventions*
- *If you use a control ray for selecting things, make sure all your menus work well with the ray. Your user is likely to be confused if they have to switch to another input mechanism such as swiping on the touchpad.*
- *Don't force users to learn a new pattern specific to your app for common interaction when the standard pattern is sufficient*
- *Use familiar UI patterns. Take advantage of your users' knowledge. If there's a standard UX interaction model for a certain action, such as tapping or dragging, use it! You won't have to teach the user a whole new way to perform simple tasks, and you can dive right into the important part of your experience.*
- *Aim for visual consistency. The visuals used for instructions, surface detection, and within the experience itself should share a single consistent look. Aim for visual harmony in all parts of your experience*

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Obstacles In Implementing and Integrating Self-Sovereign Identity and Proposed Solutions

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***Abstract*—Self-Sovereign Identity is an approach to handling identity documents in a user-centric manner around user consent. Specifically, identity documents are always controlled by the user they identify, and any operations involving them are carried out by the user. This is in contrast to existing models of identity management where information is stored and processed in a centralized manner by an external party. This approach gives rise to many applications including service authentication, cross-border travel, education focused credentials, and other user-centric technological use cases. However, work is still required for these applications to become reality. One of the key issues is that a fragmented standards space hinders efficient product building. A potential consequence is the emergence of compartmentalized ecosystems, which would drastically decrease systems' user-friendliness. This paper lays out obstacles faced in implementing and integrating SSI, including interoperability issues, and suggests how the situation could be improved.**

***Keywords*-Digital credentials; Identification; Decentralized; Standards; Interoperability.**

I. Introduction

As online services become more and more integrated into daily life, concerns about security and privacy become more relevant. More often than not, a service requires authentication, be it for access to paid services or simply access to the history and data of the user. The traditional way of handling authentication, usernames and passwords, has serious flaws: having to use multiple passwords either leads to repetition (which poses a security threat), or makes accessing services cumbersome. Single Sign-On (SSO) offers a solution to this issue: a user only has to remember one password, and the corresponding identity can be used to authenticate to multiple services. A number of standards have been established in this area, including OpenID Connect. However, this approach still means that user data is stored by a centralized authority.

Self-Sovereign Identity (SSI) aims to improve on the SSO approach by making the user (whose identity data is being handled) sovereign over that data. Technically, this means authenticating using Verifiable Credentials (VCs), which contain user information. The credentials are stored by the user and only used at the user's discretion. In addition to plain user data, the credentials can also contain other sensitive information, such as travel documents, without the user having to relinquish control of them to any identity provider. This opens up the possibility for further applications in a privacy-preserving manner.

A natural question is how one can prove their identity in this setup, where the credentials are controlled by the user. The answer is twofold. First, VCs identify their owner

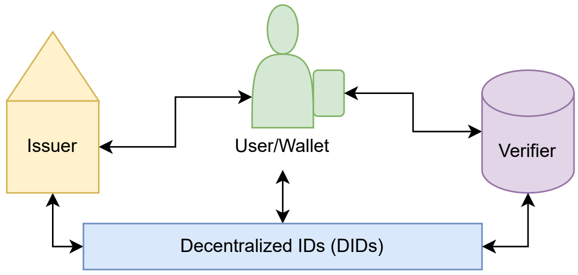

Figure 1. Self-Sovereign Identity

by use of a Decentralized Identifier (DID). A DID allows the creation of a persistent identity that is not linked to any centralized authority. There are multiple different DID methods for achieving this goal, from traditional public-key cryptography to blockchain-based solutions. Second, trusted issuers can vouch for the identity of a user. For instance, a government will only issue a passport VC to a user it has identified as the one holding the given passport. In comparison to other digital identity frameworks (e.g. government-issued eID solutions) SSI has the benefit of being decentralized and so the interoperability across borders may be considered less challenging.

The SSI approach is still relatively new, and the ecosystem is still taking shape. The unique benefits SSI can bring for users are only achievable if systems are interoperable, as described in Section III. Standards are a great starting point for interoperability, fortunately there is a rich standards ecosystem for SSI, as described in Section IV. Even though standards exist in this space, there are major areas of friction when attempting to integrate different systems, as we have faced in a project implementing SSI for authentication. The challenges mainly relate to the flexibility in encoding formats, and are described in detail in Section V. We believe that these obstacles may cause major issues for the establishment of an SSI ecosystem, and in Section VI we describe approaches, mostly related to clarity in metadata and standards texts, for lessening this impact.

II. SSI

The original concept for SSI is defined by [1] and further refined by [2]. Essentially, the following principles were defined:

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- Existence: Users must have an independent existence beyond digital systems.
- Control: Users must control their identities and how they are used.
- Access: Users must have access to their own data without intermediaries.
- Transparency: Systems and algorithms managing identities must be open and transparent.
- Persistence: Identities should be long-lived and ideally last indefinitely.
- Portability: Identities should be transportable across different systems.
- Interoperability: Identities should work across various platforms and technologies.
- Consent: Users must agree to how their identity data is shared and used.
- Minimization: Identity systems should only collect and share necessary data.
- Protection: Users' rights and privacy must be safeguarded.

To fulfill this promise, a set of technologies have been proposed. For handling identity, the technologies of decentralized identifiers and verifiable credentials can be used.

VCs are objects that encode verifiable information about a user. Fundamental to the SSI approach is a separation of the actors into three distinct groups: wallets, issuers and verifiers, which can be seen in Figure 1. The wallet is where a user stores their credential. The issuer is the party that issues credentials to be stored in the user wallets. The verifier is then in charge of checking whether a given credential is valid. All three have to interact for the system to work.

An example of this setup in action is a university diploma and can be seen in Figure 2. After a student graduates, they may want to receive a digital diploma, which they can use in the future to prove they have graduated (for instance when applying for jobs, or applying for a further degree). Following an SSI approach, the student should wholly control how they use the diploma after it is granted: there should be no need to go back to the university each time (and for instance let them know what jobs the student is applying to). For this reason, the student should have an SSI wallet, which is independent of the university.

To receive a university diploma VC, the student would then interact with an issuer tied to the university, the party that is authorized to issue such diplomas. After the student has shown that they are indeed entitled to a credential, the issuer creates and signs a credential tied to that student (through their unique DID), and sends it to the user. After this point, the credential is controlled by the student. For the credential to be useful, anyone it is presented to should be able to confirm it was issued by the university to this person. This is where the verifier becomes relevant. They are in charge of verifying that the credential is valid, and that this student has indeed graduated from the university.

This sort of setup is useful for making it clear how the roles of the wallet, issuer and verifier are different entities. There

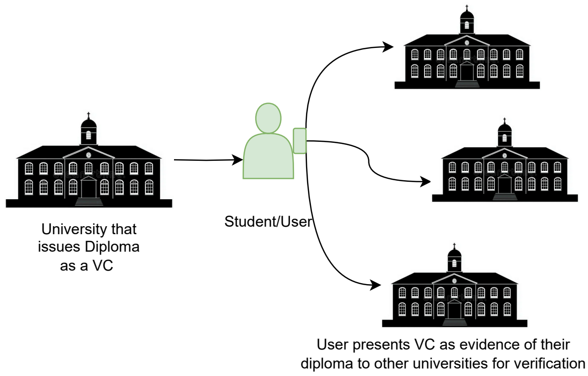

Figure 2. User-centric University Credentials

might also be setups where the issuer and verifier are the same entity, for instance if the credential in question is used to log in to only one service. In the SSO use-case, we could also have a setup where one entity issues credentials that are accepted for login purposes by multiple different services. It is clear that this setup requires that the three parties (the wallet, issuer, and verifier) have ways of communicating with each other.

There are two core security and privacy issues to take into account here. First, it should be impossible for anyone to convince a verifier they hold a credential when they don't. Second, the user should as far as possible be able to keep their personal data private for as long as they prefer.

For the first point, cryptographic tools, such as digital signature algorithms are used. Each credential is signed by the issuer, and this signature is what allows the verifier to determine that the credential indeed has been issued.

For the second, the decentralized approach goes a long way: the user only has to interact with the issuer once. There are functionalities that go further than this, for instance zero-knowledge proof based approaches, which allow the user to only reveal part of the information in the credential.

Various practical use cases exist for SSI in the academic literature, namely for blockchain-based identity and access management systems for IoT focusing on smart vehicles [3], addressing banking challenges in Know Your Customer (KYC) process [4], mapping SSI concepts to the healthcare domain [5], application of SSI in event ticketing systems [6], mobile SSI access control systems enabling secure peer-to-peer communication without internet connectivity [7], facilitating secure identity verification for decentralized energy systems [8], digital identity management [9] and facilitating border control access and travel data inspections [10].

For these use cases, SSI provides industry-specific benefits: in IoT, SSI can improve autonomy and resilience of the devices, whereas for the banking sector, SSI enables compliance adherence and efficiency of operations. For healthcare, an essential attribute is naturally privacy, for which SSI can be used to improve. In ticketing and related recreational applications, SSI can prevent fraud, and for access control, SSI's benefit is to maintain resilience.

A. *SSI as a user-centric technology*

As described previously, SSI is at its core a more user-centric version of existing SSO solutions. This solution is more user-focused in three main ways: it allows the user flexibility, it prioritizes user control over their data, and it enables them to protect their privacy.

Due to the decentralized setup, the system provides flexibility to users. They can choose from a number of wallet applications, which may have different features, but are still able to receive and use credentials from any issuer.

SSI prioritizes user control over their personal data. Credentials are stored in the user wallet, and only shown to others when the user expressly consents to. On a technical level, this is achieved by using a *self-issued OpenID provider*. The user is able to make claims about themselves (possibly leveraging credentials they have previously received) without having to pass through an OpenID provider as is traditionally done in SSO setups.

Other functionalities can protect user privacy even further. Approaches based on zero-knowledge proofs can allow users to only reveal a subset of the information contained in their credentials, and wallet applications can keep track of the information revealed by users to ensure that not too much is revealed to any one party. Overall, the decentralized approach of multiple interoperable wallets allows wallet applications to cater to user needs both in privacy and for general user interface behaviour.

In terms of identity revocation in SSI, standards, such as [11] do not define specific revocation format or method. There exist several approaches to implement revocation in SSI, but a common system-wise challenge is that the mechanisms usually rely on some kind of centralization, which is in conflict with the basic principles of SSI [12]. Basically, implementations for revocation of identity are often based on the revocation lists similar with those familiar to Public Key Infrastructures (PKIs), often combining cryptographic accumulators with the mechanism. Another path is to build and utilize dependencies either between VCs, or between Issuer and Verifier, in which VCs validity can be limited for example by time or other parameter(s).

III. The need for interoperability

As put forth by the original proposers of SSI, identities should be interoperable. This is important for a fundamental reason (identities as commonly understood are not tied to any one system), but is also necessary for a technical reason. If identities are user-controlled, they have to also be decentralized. A decentralized system collapses back to centralization if it is not possible for different systems to work together.

Due to the high level of effort necessary to receive documents containing sensitive personal data, user adoption is dependent on the systems to be easy to use after setup. If a single SSI wallet does not work across systems, using SSI becomes much more cumbersome.

Further, for wide adoption (which is necessary for a true digital identity) it is necessary for a large number of service providers to support authentication using SSI. If each provider has to implement the entire SSI stack for themselves, this will likely create a major obstacle. Therefore, it is important for new players to be able to rely on the existing infrastructure. This becomes much harder if the systems are not interoperable.

IV. Current standards landscape

Standards are a major enabler of interoperability. They provide a shared reference for providers to use. Fortunately, SSI already has well-established standards. Roughly, the standards can be broken down into four layers: technical, credentials, identity, and institutional. See Table I for a list of standards.

On the technical level, standards describe the way data is encoded. IETF has standardized JSON Web Tokens & Signatures (JWT & JWS) [13], which can be used to encode verifiable credentials. A different format, JSON-LD, has been standardized by W3C. The multicodec protocol, partly standardized by W3C, can be used to flexibly encode key material, which is necessary when defining DIDs.

These standards don't yet define the objects relevant to SSI. The necessary standards for SSI are defined by W3C, which standardize the core verifiable credentials data model [11], as well as various extensions of it. When combined with standardized encoding formats, it is then possible for parties to store, send and process verifiable credentials in a standardized way. In addition to defining the credential, these standards also define verifiable presentations, which is a format credentials are converted to in order to be presented to a verifier.

To be able to use these credentials, standards are still needed to describe how parties exchanging the credentials should operate. Here is where the OpenID Foundation standards [14] come into play. The protocols for both issuing and verifying credentials are heavily based on existing OpenID standards. The SSI-specific ones include OpenID for Verifiable Credential Issuance and OpenID for Verifiable Presentations. These define OpenID-based flows for a user to receive a credential (after authentication) and for authenticating using a verifiable presentation in a way interoperable with existing OpenID-flows.

The above flows leave some details open in the interest of future flexibility. This creates an issue for institutional players that would like to support the use of SSI. Consequently, various institutional players have stepped in to further specify interoperability conditions in given context. In the EU, EBSI [15] has defined a set of conformance tests for software, which specify the interaction between the components, and the EU digital identity wallet places requirements for member states in the EU [16]. In the private sector, organizations like the International Data Spaces Association [17] and GAIA-X [18] define SSI use together with data spaces.

V. Obstacles to integration

As laid out in Section IV, interoperability is necessary for self-sovereign identity to become a reality. This requires

TABLE I. STANDARDS AND ENTITIES RELEVANT FOR SSI

Standard	Layer	Role	Standards body or Entity
JOSE	Technical	Defines basic data objects	IETF
JSON-LD	Technical	Format for data objects	W3C
multicodec	Technical	Encodes key data	W3C
Verifiable Credentials Data Model	Credentials	Defines basic credential and presentation data formats	W3C
OIDC	Identity		OpenID Foundation
EBSI	Institutional	European Blockchain Services Infrastructure	European Commission
DID	Identity		W3C
EU digital identity wallet	Institutional		European Commission
IDSA	Institutional	Standards organization	International Data Spaces Association
GAIA-X	Institutional		GAIA-X Association

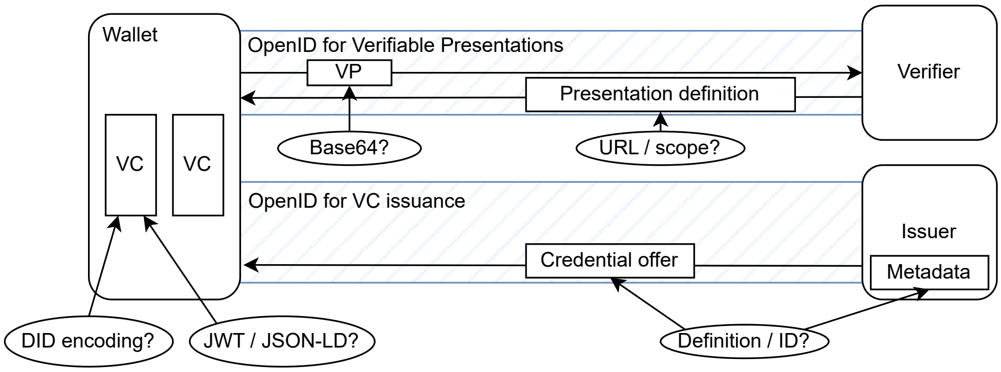

Figure 3. Diagram of problematic ambiguities in SSI flows. Each oval label identifies an area of divergence across implementations. See Section V for detailed explanations.

integration between various components. However, there are multiple obstacles to this integration work.

In this section, we point to places where the friction is especially high. Many of these have to do with incompatible formats. These issues were identified in the context of the Horizon Europe project TANGO [19], where the end goal was to use SSI for authentication in a data spaces settings. See Figure 3 for an overview.

The major issues caused by these obstacles are:

1) Friction when integrating systems, slowing down development work.
2) Technical impossibility, given time constraints, of making two systems interoperable.
3) Making projects harder to maintain due to needing code purely for compatibility reasons.

Overall, these issues reduce innovation by slowing down development work, and may lead to the establishment of non-interoperable ecosystems. For instance, friction caused by unclear formats might cause significant resources to be spent troubleshooting the issue.

A. VC format

The basic data structure of a verifiable credential is defined by the W3C. However, this standard is agnostic as to the encoding of a credential. Two major competing encodings are JWT and JSON-LD. Both are JSON-based, but provide very different mechanisms for proving the authenticity of the credential. A software component that supports credentials in one format will not work for the other. As some functionalities, especially ones using advanced authentication technologies, are only available in one of the formats, they might fail to be supported in some systems. This increases the amount of work required for a software provider if they are to be interoperable with all systems. If two different providers use different formats, the user might well miss out on functionality important to them, for instance the use of zero-knowledge-proof enabled credentials. Further, they may need different versions of the *same* credential in different contexts, making the system cumbersome and less intuitive.

B. DID key encodings

With some DID methods, especially `did:key`, there is a need to encode a public key. This public key is to be read by the verifier when assessing whether the credential is valid. However, there are multiple different encoding formats for the key, even when the underlying algorithm is the same. This again forces providers to support each type, or risk hard-to-debug errors.

C. Presentation format

In order to use a verifiable credential, it needs to be converted to a verifiable presentation. In the `vp_token` flow, this verifiable presentation is then sent to the verifier for checking. However, the exact format this presentation takes can differ. It can be sent as a JWT, or that JWT can be encoded as a base64 string (which further can differ, e.g., whether it is URL-safe, and how padding is handled).

D. Breaking metadata changes

During the issuance flow, the credential issuer needs to expose some metadata itself, for instance to advertise the types of credentials it offers. However, there have been changes to this mechanism in the drafts of the relevant standard. In older versions, this information was contained in the credential offer itself, but later versions opt for an approach where the credentials offered are defined in the metadata of the issuer, and the credential offer identifies the credential being offered via an ID. This creates challenges especially in wallets that follow a frontend-backend architecture. In the first approach, the credential offer contains everything needed to describe the credential to the user. In the second, fetching of the information becomes more complicated, since the metadata of the issuer has to be specifically accessed.

E. Scope vs presentation definitions

When a verifier describes the type of credentials it is expecting, it has various different ways of doing this. A `presentation_definition` (possibly accessed through a `presentation_definition_uri`) describes the contents expected of the credential. However, the verifier can also make use of a `scope`, which is an arbitrary string that refers to some credential. However, this "scope" is hard for a wallet to be interoperable with, since the vocabulary is not defined in standards. To support a verifier that describes credentials using a scope, it is necessary to first define the meanings of the scopes between the organizations providing the wallet and verifier, and second for the wallet to specifically implement these scopes to properly support them.

VI. Solutions: what would help

The previous section outlines various integration obstacles observed when attempting to implement an SSI system in practice. This section contains proposals for changes in the landscape that would make integration work more seamless, and make it more likely for SSI to be used widely.

There are two main actors can help integration work: standardization bodies and technical specifications. The solutions suggested in this section apply to both, as well as the *drafts* of standards that currently are being used to build interoperable SSI systems.

> Standard and draft versions should be included in machine-readable metadata of applications implementing SSI.

A major hurdle is uncertainty over the draft version of standard implemented by any given application. This can break interoperability either since there are breaking changes, or because a newer draft includes a new functionality. The draft version being clearly communicated in machine-readable metadata would make things smoother. Software could robustly pick the draft version to use, or at least give a clear indication of the issue (unsupported draft version). This would make it much easier for actors to develop systems, and stress-test the standard drafts themselves. This is especially relevant in the draft phase, where changes happen frequently.

> Standards and technical specifications should together include exact technical details necessary for interoperability.

Standards support integration work as an intermediary between organizations by providing a common flow for them to agree on. Organizations can ideally build interoperable systems with little or no back-and-forth communication. However, this benefit is greatly reduced if the exact technical details are left out. This can cause issues that are hard to troubleshoot. This can to some extent be covered by standards themselves, but part of the work is left to technical specifications.

> Standard drafts and technical specifications should clearly state which details are settled and which are not.

It is not always feasible or desirable to define all technical details. The standard might only be in the drafting phase, where work put into deciding and specifying technical details might be wasted if the final approach ends up being different. The authors of the standard might also want to avoid over-specifying the technical solution. This can leave space for innovation, support more use cases, or leave flexibility in case of further changes. For instance, setting in stone specific cryptographic signature algorithms would cause major issues if there were to be a need to change these (as in the case of the transition to post-quantum cryptography), and as such it is common practice to define these outside the standard itself. In any case, such areas where technical details are not (yet) agreed on, this should be made as clear as possible. This way organizations wishing to build interoperable systems have a clear basis for discussions. Further, it would be useful if there were a mechanism for implementations to communicate the specific choices made. Software can then adapt to the specific choices within the implementation.

> A standard draft should specify any significant point which differs from those in a previous version.

This would help application developers update their systems as required. Version history is often provided in standard

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drafts, but it would be especially helpful if these changes were communicated in machine-readable metadata.

> Requirements related to user privacy should be set clearly by either standards or technical specifications.

SSI enables the use of many privacy-preserving technologies that can help users keep their data private. However, these technologies may require, for instance, the use of a specific format to store a credential, which in turn might not be supported by all wallets, issuers, or verifiers. This puts the user in a difficult position: they have adopted a technology, which promises them privacy, but in practice these functionalities might not be available. If full convergence of the standards is not feasible, actors wanting to support the takeup of SSI should place clear requirements for protection of user privacy, so that users can trust that the promise of user privacy is actually fulfilled.

VII. Conclusion and Further Work

SSI is a promising identity technology, which can offer improvements to user experience and privacy. Due to the nature of SSI as a decentralized technology, interoperability is of great importance. Even though there is a robust set of standards for the different aspects of SSI, there are caveats that cause significant friction when integrating SSI systems in practice. We believe there are a number of approaches that could be taken now to make these systems easier to integrate, and consequently to foster further innovation in the space.

This paper is based on experiences gathered during our participation in the Horizon Europe TANGO project, with one set of software components. Determining if these issues are widespread, and identifying the obstacles faced in other projects could provide valuable input for standardization bodies. Furthermore, collecting feedback from a diverse set of stakeholders, such as wallet developers, end users, or institutional issuers would also be beneficial to the development of the SSI ecosystem. All of their differing perspectives could validate and contextualize the identified issues.

In future work, a cost-benefit analysis of the value brought by flexibility vs the cost imposed on integration efforts might allow for stronger recommendations for clarity in standards than the ones presented here, which defer to the value of flexibility.

Acknowledgment

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