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Contents

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Guest Editor's Introduction

HUMANIZATION OF DIGITAL TECHNOLOGIES

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Abstract: *This editorial introduces the special issue arising from the "11th International Conference on Communities and Technologies - Humanisation of Digital Technologies". It sets the stage for a series of papers that illustrate a shift from technology-centred to human-centred approaches in the development of digital technologies. The editorial highlights the central theme of the conference, emphasising the integration of human needs and values to enhance societal well-being and environmental sustainability. It outlines the overarching goals of humanising digital technologies, discusses the significance of each of the included papers in advancing these goals, and emphasises the importance of ethical considerations and user-centred design. This issue demonstrates practical approaches to embedding human values at the core of technological innovation, ensuring that digital technologies serve societal needs and support inclusive and sustainable development.*

Keywords: *humanisation, technological innovation, sustainable development.*

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Towards a More Human-Centered Digital Future

In today's digital age, the interface between humans and technology not only shapes our interactions with machines but also deeply influences our social structures and personal well-being (Ahmad et al., 2022; Murray et al., 2021). The 11th International Conference on Communities and Technologies (C&T 2023), themed "Humanization of Digital Technologies," invited participants to critically reassess this dynamic interaction. This theme advocates a shift from a technology-centred to a human-centred perspective, urging us to consider technology as embedded in the broader context of human needs, values and ecological considerations.

Central to this discourse, and reflected in the papers selected for this special issue, is the concept of human-centred design. This is a design philosophy that prioritises the human experience in the development of technology, with a focus on enhancing human well-being and capabilities rather than simply increasing technological functionality. By involving users directly in the design process, as advocated by Norman & Stappers (2015), technology becomes more than a tool, but a natural extension of human activity that resonates deeply with individual and communal needs. The papers in this special issue embody this approach, each exploring different facets of how technologies can be more thoughtfully integrated into our lives. Complementing this is the concept of post-digitalism, which reconciles the role of digital technologies in everyday life. As outlined by Cramer (2015), this perspective acknowledges that the disruption caused by digital technologies has already occurred, and shifts the focus from technology as disruptor to technology as integrator within society. This perspective encourages technologies that adapt to and enhance human practices, rather than overshadowing or replacing them (Cramer, 2015; Jandrić et al., 2018). Building on these foundations, the integration of artificial intelligence (AI) into this framework represents a considerable step forward in the humanisation of digital technologies (Siemon, 2022), as collaboration between humans and AI is an example of this potential transformation. For example, Dignum (2019) highlights the need for AI systems that respect human autonomy and promote societal values. Such systems should empower humans rather than replace them, creating a symbiotic relationship (Gerber et al., 2020) in which human intuition and emotional intelligence synergize with AI's computational capabilities to address complex challenges (Dellermann et al., 2019; Gerber et al., 2020).

In addition, the humanisation of digital technologies involves a sophisticated interpretation of data, in which human insights play a critical role (Wolff et al., 2016). This process goes beyond mere data analysis; it involves an ethical and contextual assessment of how data impacts real-world scenarios. This is particularly important in areas such as healthcare, urban planning and environmental protection, where the impact of technological decisions can be profound. The ongoing interplay between these concepts - human-centred design, post-digitalism, AI collaboration and ethical data use - highlights the complexity of humanising digital technology. Research in this area must therefore navigate these different relationships and develop technologies that are not only innovative, but also deeply integrated with human and ecological values. In this way, researchers and technologists can ensure that advances in ICT not only solve technical problems, but also enhance societal well-being, promote inclusivity and foster sustainable relationships with our environment.

Humanising digital technologies means recalibrating our approach to innovation, putting human and environmental well-being at the heart of technological development. Through

thoughtful research and deliberate design, we can create technologies that truly serve society, improving the human condition while respecting the delicate balance of our world.

Papers of this Special Issue

This special issue, arising from the 11th International Conference on Communities and Technologies - Humanisation of Digital Technologies, presents a collection of extended papers that push the boundaries of how digital technologies can be centred on human needs and societal values. These papers, while diverse in their focus, underscore the importance to design and use technology in ways that enhance human interaction, societal engagement, and ethical considerations. Each paper not only contributes unique insights into the application of technology, but also aligns with the overarching theme of humanising digital technologies.

"Self-Sovereign Identity, Data Control, and User Perceptions" by Martin et al. explores the limitations and potential of Self-Sovereign Identity (SSI) technology. Contrary to claims that SSI offers users greater control over their data, the findings suggest a more nuanced reality, particularly in the absence of supportive regulatory frameworks such as the GDPR. This paper critically addresses the balance between user autonomy in data management and the institutional power dynamics that influence this autonomy, highlighting a core aspect of humanising technology: the need for user-centred privacy and control in digital identity systems.

"Using Empathic Design Strategically to Provide Citizen-Friendly Services" by Hyökki et al. describes the application of empathic design principles in Finnish cities to better meet the diverse needs of their citizens. By placing the human experience of city residents at the forefront, this study shows how city governments can move from being service providers to facilitators of inclusive community spaces. The strategic use of design thinking in public services reflects a commitment to creating responsive and adaptive urban environments that prioritise the well-being of citizens.

"The Role of Digital Technologies in Urban Co-Creation Practices" by Slingerland et al. explores how digital tools can facilitate participatory design and co-creation in urban planning. The paper highlights the potential of digital technologies to bring together diverse community voices in the design of urban spaces that are equitable and responsive to local needs. By analysing European case studies, it demonstrates the transformative power of digital tools in promoting collaborative urban planning, thereby enhancing community engagement and social inclusion.

"Designing Shareish, an Open-Source, Map-Based, Web Platform to Facilitate Diverse Solidarity Practices" by Guilliams et al., presents a platform inspired by the gift economy to support community solidarity. The open-source nature of Shareish, and its focus on localising resources and commitments, demonstrates how digital platforms can foster community autonomy and empower local interactions. This approach to technology design prioritises accessibility, community ownership and the facilitation of grassroots movements, closely aligning with the theme of humanisation.

"Artificial Intelligence and Machine Learning Combating Illegal Financial Operations" by Leonov et al. illustrates the critical role of AI in improving the detection and prevention of financial crime. Through the use of advanced analytics, this paper discusses the capabilities

and challenges of AI in a regulatory environment, highlighting the importance of ethical considerations and transparency in the use of AI. This is in line with the theme of ensuring that technological advances in AI contribute positively to societal security and justice.

CONCLUSIONS

The insights gained of the 11th International Conference on Communities and Technologies (C&T 2023) and the papers in this special issue highlight the need for a shift in the way digital technologies are conceived and implemented. This movement towards the humanisation of digital technologies is a broad challenge that requires a re-evaluation of our technological priorities and strategies, with the aim of placing human and ecological well-being at the forefront of technological progress. The papers in this issue illustrate different implementations of human-centred design principles in different contexts - from the study of self-sovereign identities to the application of empathic design in urban planning. Each article highlights the importance of prioritising human experiences and needs in technology development, and offers strategies for how digital tools can enhance community empowerment, protect individual rights and promote inclusivity.

Discussions on AI, particularly in regulatory contexts such as the prevention of financial crime, highlight the need for a balanced approach to technological innovation that incorporates rigorous ethical considerations. These discussions point to the importance of creating AI systems that are transparent, accountable and aligned with societal values, thereby mitigating potential risks associated with the use of AI (Arrieta et al., 2020; Brendel et al., 2021; Dignum, 2019). Humanising digital technologies requires a multidisciplinary approach, combining insights from design, ethics and technology development. It requires a commitment to continuous research and collaboration across disciplines to ensure that technological advances make a positive contribution to society. This approach should include rigorous evaluation mechanisms to assess the impact of technologies on human and environmental health.

In conclusion, the quest to humanise technology is an invitation to innovate responsibly. It requires researchers, practitioners and policy makers to engage in sustained dialogue and collaboration to develop technologies that are not only effective, but also equitable and sensitive to the complex dynamics of human and ecological systems. The papers in this special issue contribute to this dialogue by offering fundamental perspectives and methodologies for advancing this critical field.

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THE CHIMERA OF CONTROL: SELF-SOVEREIGN IDENTITY, DATA CONTROL, AND USER PERCEPTIONS

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Abstract: *This paper analyses the claim that Self-Sovereign Identity technology (SSI) gives users greater control over their data and identity than established digital identity systems, and studies empirically how users view this claim and its impact on adoption decisions. We argue that the claim is objectively false. SSI does not offer users greater control over their data, though in combination with laws like the GDPR, certain add-on features to SSI might have mildly privacy-/control-enhancing effects. Absent GDPR-like laws, however, SSI threatens to turn into a "disclosure machine" where users are forced to give up more data than they would likely have (or be able to) with extant identity solutions. SSI attempts to solve political-institutional problems through technology/architecture, but cannot eliminate the power imbalances at the heart of users' lack of control. Presented with an SSI system, we find that most users do not seem to intuitively conclude that it gives them "control" over their data. A minority does however reach this conclusion, and for these people it seems to be an important factor driving adoption decisions.*

Keywords: *Self-Sovereign Identity, SSI, privacy, data protection, institutions, GDPR.*

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INTRODUCTION

Self-sovereign identity solutions (SSI) have attracted much attention. In the Horizon 2020-funding period, European Union (EU) funding for SSI-related research projects ran to at least ~€45 million.[1] Member states too are funding SSI-related projects with large sums.[2] Numerous start-ups are developing SSI-style identity solutions. Major business groups have expressed strong support for SSI (e.g. Deutscher Sparkassen- und Giroverband et al. 2021). International organisations like the World Food Program have also explored SSI for working with refugees.

Advocates of SSI claim that it offers several benefits compared to traditional digital identity solutions, including greater security and usability (Kubach et al. 2020), greater personal privacy (Schardong and Custódio 2022), allowing users "to fully own and manage [their] digital identity" (Mühle et al. 2018, p. 81), and stimulating the digital economy (Echikson 2020). SSI proponents have even claimed that it could help solve the problem that lack of identity documentation poses for undocumented migrants and/or support economic inclusion (Lim 2020, Wang and De Filippi 2020).

The key benefit of SSI that its proponents reference, though, is that it would put users *in control* of their data and identity. This greater control over one's own data and identity is what supposedly fundamentally distinguishes SSI from other identity solutions – hence its name "*self-sovereign* identity".

Surveys indicate that the idea of getting more "control over one's data" is very popular among users (PWC 2021, Spiekermann and Korunovska 2017). Probably for this reason, business interests have adopted the language of giving users "control over their data" to promote SSI (e.g. Schorlemer 2022).

This paper analyses whether the claim that SSI gives users meaningful control over (i) their data and (ii) their identity, is factually correct. We argue that while SSI advocates' claims are not without grains of truth, they are greatly overblown. SSI can offer users small increases in control of their data, but only if a suitable legal framework is in place, like the GDPR. Where such a legal framework is absent, SSI solutions on the contrary regularly risk compelling users to disclose more data than they otherwise would.

The paper then investigates users' perceptions and responses to the claim that SSI gives them "control", asking two empirical research questions:

> RQ 1: Irrespective of the *objective* truth of the claim that SSI gives users control, do users *subjectively* conclude that SSI *will* put them in control of their data, if the basic functionality and data flows in an SSI system are explained to them?[3]
>
> RQ 2: In as far as users do conclude that an SSI system gives them "control", how important is this for driving adoption?

To our knowledge, the scholarly literature has so far largely failed to critically analyse the claim that SSI gives users "control" over their data or identity. A growing body of work exists on SSI systems (e.g. Strüker et al. 2021, Sedlmeir 2021, Richter and Anke 2021, Liu et al. 2020, Lim 2020, Kubach et al. 2020, Hempel and Anke 2023), but this largely focuses on technical aspects, and occasionally on business models. It and tends to assert, rather thannot critically interrogate, SSI's capacity to give users "control". An exception is a recent Master's thesis (Doesburg 2023), which notes that SSI can encourage "oversharing" of data and

proposes technical measures to ameliorate this problem.[4] But by focusing on technical measures, it falls into the same as trap as, we will argue, SSI advocates have fallen into, namely trying to solve what are fundamentally political-economic challenges through technical fixes.

It is from activists, rather than academics, that the problem of user control in SSI has received greater attention. Thus a policy submission on the reform of the EU's eIDAS regulation (*Regulation on electronic identification and trust services*) from epicenter.works, a digital rights NGO, develops a similar analysis of the potential for abuse of digital wallets as that advanced here. However, it is focused on specific issues with eIDAS and does not attempt a systematic analysis of the concepts of "controlling" one's data or "identity". Instead, it mainly concentrates on proposing alterations to specific parts of the legal text (epicenter.works 2022).[5]

To our knowledge, only the consulting company PWC has investigated to what extent users value SSI's promise to give them "control" of their data. PWC surveyed 2,000 German consumers on their views about digital wallets, which are a component of most SSI systems (see below). PWC found that for 92% of respondents, it is "very" or "somewhat" important to be able to decide themselves about "which data they disclose". For 90%, "sovereignty over storage and use of data", is a "very" or "somewhat" important product feature of digital-wallet systems (PWC 2021). Beyond these two data points, however, the PWC survey provides no further information on users' perceptions and responses to actual SSI systems. Moreover, it does not analyse the data statistically. We are not aware of any other studies that have collected and explored empirical data on how (potential) users of SSI solutions view these questions.

The issues addressed in this paper matter for several reasons. If SSI does not in fact provide users with meaningfully greater control over their data than other identity systems, then advocates promoting SSI on this basis at minimum risk overselling these systems, if not actively and dangerously misleading users. As Doesburg (2023) warns, users may be particularly prone to "oversharing" data if they (falsely) believe that SSI is especially privacy friendly. Misleading advertising risks luring them into a false sense of security.

Users' general cynicism about tech company claims might mitigate the risk posed by misleading claims. An arguably greater danger is that SSI developers and policy makers come to believe their own hype, about SSI solving a series of social-political problems, and doing so by means of a clever technological architecture. If SSI does *not* in fact do so, this would leave the real problems unaddressed. Worse, it risks exporting technological solutions dependent for their safety on specific legal frameworks (e.g. the EU General Data Protection Regulation [GDPR]) to countries where this framework is lacking and the tech solution in question may in fact exacerbate rather than reduce risks, while claiming that the technology has solved these risks.

As we will see, this is precisely the case: Absent legal-institutional safeguards like the GDPR, structural power imbalances between users and service providers can transform the architecture of SSI from a (mildly) privacy-*enhancing* technology into a "disclosure machine", where users are forced to give up more data about themselves than they would likely have to (or be able to) with either centralised or federated identities. This problem emerges particularly clearly with refugees, a potential use case for SSI systems highlighted by several prior authors (Wang and De Filippi 2020, Cheesman and Slavin 2021), but it also

exists for other users. The reason for this is that SSI solutions do not and cannot eliminate the larger imbalances of power in the (digital) economy and the state, that are at the heart of users' lack of control over their data and identity. SSI proposes a technological and architectural solution to what are ultimately political-economic and institutional problems. Accordingly it falls short. For this reason – contrary to some SSI advocates' claims – SSI also cannot solve the political problem facing most undocumented migrants, that no state is willing to issue them with valuable identity rights.

Finally, if this paper's conclusion that the "control" SSI grants to users is largely chimerical is correct, it is to be expected that users will soon see through this promotional rhetoric. As we will see, this is supported by the results for RQ 1. That would be bad for SSI – which arguably does offer users real economic and usability benefits – and for the general level of trust in society. If consumers come to feel misled about something as fundamental and intimate as their control over their own data and identity, this may have more damaging consequences than if they feel they have been sold an overhyped golf club or other random consumer gadget. The good news for SSI advocates is that the findings with regard to RQ 2 suggest that exaggerated claims about control are not needed for driving adoption.

METHOD AND STRUCTURE

The paper has two parts. Part One investigates the claim that SSI provides users with "control" over data and identity. It first provides a conceptual and literature-based analysis of the concept of having "control" over one's data and identity. To analyse this concept, the paper focuses on how it is operationalised in the GDPR. The GDPR offers a useful lens because safeguarding individuals' control over their data (informational self-determination) is one of its core objectives and it represents the most developed attempt to operationalise this concept in practice for the digital world. It also constitutes the central legal framework within which SSI solutions, at least in Europe, have to work and be designed for.

Next, the paper describes how SSI solutions try to provide users with "control" by technological and architectural means. SSI is compared to two established types of identity system: centralised and federated identity management systems. This analysis is based on the extant literature describing these different identity systems, plus in-depth discussions with SSI developers from the Spanish research organisation GRADIANT.[6]

On this basis, the paper shows why the promise of SSI largely falls short, with the (distinctly modest) improvements in user "control" that SSI solutions may sometimes be able to achieve dependant entirely on the existence of legal protections for users – not the technology as such (as SSI advocates tend to claim). The paper then turns to the problem of situations where these legal protections are absent. For this, it re-analyses a case study presented in Wang and De Filippi (2020) to show how under these circumstances, SSI risks turning into a "disclosure machine" that weakens, not strengthens, user control. Summary conclusions with regard to SSI's claim to provide users with "control" are then presented.

Part Two investigates empirically how users perceive and respond to the claim that SSI gives them "control" (RQ 1 and RQ 2). To answer these research questions, data from a unique user survey (n = 740 and a subset thereof) is analysed. A detailed description of the survey instrument, data and analytical method are presented in Part Two.

PART ONE: "CONTROL" IN SSI SYSTEMS

Data, Identity and Control

Control over One's Data

Since the German Constitutional Court's 1983 ruling establishing a right to "informational self-determination", the idea that users ("data subjects") should "control" their data has become increasingly central to European debates about data policy and data protection. The Court ruled that individuals should in principle be able "to determine for themselves when, how, and to what extent information about them is communicated to others." (Lazaro and Le Métayer 2015: p. 6; also Veil 2018). This idea, that individuals should have the power to decide over the use and disclosure of their data (Gonzalez Fuster and Gellert 2012), has since become a cornerstone of European data protection law and the EU General Data Protection Regulation (GDPR) in particular. As Clifford and Ausloos (2017) note, "control" here must be understood broadly, as providing "a robust architecture of control that actively ensures individual autonomy."

The GDPR tries to implement this through two mechanisms (Vogiatzoglou and Valcke 2022). Firstly, it equips the individual with a battery of so-called "data subject rights", vis-à-vis data controllers (e.g. online service providers). Users have rights to information and access about the use of their data (Art. 12–15 GDPR); to rectification of erroneous data, erasure ("to be forgotten"), and to restrict or object to processing of their data (Art. 16–18, 21), among others.

The second mechanism by which the GDPR tries to safeguard the individual's control over their data is by specifying the legal bases under which personal data can be legitimately processed (Art. 6). In particular, it defines the conditions under which the data subject may be said to have "consented" to processing (Art. 7). This is crucial, as consent remains one of the most common legal bases for processing. However, consent may often provide a particularly flimsy safeguard, or means of control, for the individual. This flimsiness is due to how, in the digital world, nominal "consent" can and often is obtained through power imbalances (take-it-or-leave-it offers) and even manipulation. To prevent this, the GDPR specifies that "consent" must be "freely" and demonstrably given. Information about *what* is being consented to, must be presented in an "intelligible and easily accessible form, using clear and plain language". Data subjects must be able to withdraw consent at any time and this must be "easy" (Art. 7).

These stipulations show that while conceptually, the notion of having "control" over one's data is simple (to be able to determine who gets it and what they can do with it), operationally it is anything but. To have "control" while also using data-based services requires one to be able to meaningfully exercise and enforce multiple rights/capabilities vis-à-vis data processors.

The question of the effective exercise of rights/capabilities points to the weaknesses inherent in consent as a mechanism for regulating user/service provider-relationships in the digital economy. Often this relationship rests on large, even extreme, power imbalances (Lazaro and Le Métayer 2015). For many of the socially or economically most valuable services in the digital economy, few substitutes exist. Absent legal safeguards, the user is thus

left with the choice to "consent" to whatever terms the service provider stipulates, or forego the service. Depending on the value and uniqueness of the service, though, that may not be an option for the user. Furthermore, a large information asymmetry often exists between user and service provider regarding what data are being collected, and how and to what ends they are being processed.[7] Under these circumstances – which are omnipresent in the digital world – "consent" as an expression of meaningful control over data processing is likely to be an illusion. While the GDPR's insistence on consent being "informed" and "freely given" is laudable, it is questionable to what extent even this regulation has been able to do much to level the underlying power imbalance and make "consent" meaningful. This has important implications for SSI.

Control over One's Identity

Identity, and "control" over it, are trickier concepts. As Zwitter et al. (2020) discuss, there is a longstanding debate in philosophy about how to understand identity. Philosophical naturalists believe that identity is inherently "tied to the properties of an object or a person". It is "whole" and "distinguishable" from others (ibid.). In this view, identity is in effect a kind of object or "thing". By contrast, philosophical constructivists understand identity as being primarily relational. It is not so much an object as a status that arises out of the relationship of a person or an object to other persons, objects or institutions (ibid.).

This paper does not aim to resolve these philosophical debates. Arguably, "identity" has both relational/constructivist and objectivist/naturalist dimensions. This dual nature of identity – naturalist/objectivist *and* constructivist/relational, "thing" and "status" – is evident in digital and in legal-political identities. It is these that are mainly of interest here, as SSI is a type of digital identity and can also potentially serve as a digital version of offline legal-political identity documents like passports or identity cards, or at least depends on them in order to offer SSI users much of value, a point discussed further below.

Structurally, both digital identities and legal-political identities consist of:

- An *identifier* – such as a username, account number, tax number or state identity card number – that uniquely identifies the entity (the person, user, machine, organisation, …) and distinguishes it from other entities (Dunphy and Petitcolas 2018);
- *Attributes*, that is, pieces of information that describe the entity, such as their real name, age or citizenship, etc. (Dunphy and Petitcolas 2018). Attributes can also include rights or entitlements (in other words, status), such as the permission to access a certain IT system (e.g. an email inbox) or to receive a certain payment (e.g. child allowance).[8]

In as far as digital and legal-political identities are data (the identifier and attributes) encased in a digital system (e.g. an app) or a physical artefact (e.g. a card), they are "things" and can thus arguably be, in some sense, "controlled" by their holder (user). It is likely no coincidence that the SSI discourse tends to talk about identity in these objectivist/naturalist terms.[9] Practically, "control" may mean something like being able to decide how and where to use one's identity, whom to disclose attributes to, whether and how long those to whom attributes have been disclosed to may store this information, and for what purposes they may process it. It might also mean being able to decide who can add further attributes to one's

identity. This is broadly similar to having "control over one's data" (attributes are data).[10] Of course, as with data, the "choice" over whether to disclose one's identity to someone may often be largely chimerical. If I want to buy alcohol, I *will* have to show my ID.

But the practical social, economic and legal-political value of identity – which is what people are usually most interested in – is strictly relational. Identities, or rather their attributes (e.g. citizenship, status as a single parent, holder of university degree, …) usually only create value for the person who holds them because the identity/attribute is recognised by others, who agree to act on this identity/attribute in ways beneficial to its holder (e.g. grant them the right to vote, to pass a border, get benefits or a job, or access to an email system). An identity/attribute that is not recognised by others is – in social, economic or legal-political terms – largely worthless, however expressive of the holder's most deeply held beliefs it may be.

It is much less clear what having "control" over this identity-as-relationship/status might mean. The most plausible reading of "control" here would be that it means to have some degree of control or power *over the relationship*. It is not immediately obvious what this would mean practically, but it could be something like being able to *oblige* counterparties to act towards one in certain ways (e.g. grant access to an email system, pay benefits).[11] It is hard to see how any identity management technology can do that.

The Promise of Self-Sovereign Identity: Solving for Control Technologically

To understand how SSI works and tries to exploit technology and architecture to give users control over their data/identity, it is helpful to contrast it to two established, widely used identity management approaches: centralised and federated identity management systems.

In *centralised identity management systems*,[12] the user is issued with an identity by the system administrator. The system administrator retains ultimate control over how the user uses the identity and can, at least within their system, track user behaviour. Amazon is a typical example of this. To use Amazon's service (i.e., purchase books, films, etc.), the user must create an account (i.e. a digital identity) with Amazon (Figure 1, left). Amazon "controls" this account/identity, in the sense that the company can define the terms under which it may be used, monitor user behaviour on the Amazon site (and possibly also on other websites if the user stays logged in to their account),[13] and revoke the account and identity at will, subject to law. Another example of centralised identity systems are employees' user accounts/digital identities with their employers' IT systems (computer, corporate email, server access etc.). Again – subject to data protection and employment law – the employer can define the terms under which the employee may use their account/identity and the corporate IT systems, monitor user behaviour within the corporate systems, and revoke the identity. Centralised identity systems are often system-specific, like in these two examples: neither Amazon nor most employers offer users an identity that can be used with other service providers (e.g. to authenticate to an online banking service).

In *federated identity management systems*,[14] also known as Single Sign-On (SSO), the user signs up for an identity with a central identity service provider, such as Google or Facebook, and can then use the identity thus created (e.g. their Gmail address and password) to sign up for, log in to and use the services offered by other ("federated") service providers

(e.g. a music streaming service) that accept the SSO provider's identity system (e.g. "sign up with Gmail") (Figure 1, right). Federated systems give the SSO provider (e.g. Google) control over the user's identity in the sense that the provider can set the terms and conditions of use, revoke the user's identity (thus locking her out of all services she uses the SSO identity for), and can track the user across all services she accesses with the SSO identity.[15]

A number of different approaches to *self-sovereign identity (SSI)* exist. There is no single definition of the term (Kubach et al. 2020, Lim 2020). Generally though, SSI approaches share a common conceptual reference point in the work of Christopher Allen (2016), whose "ten principles of self-sovereign identity" serve as a kind of foundational text for the community. More importantly, SSI systems generally rely on the same technical building blocks and foresee similar architectures and ecosystems built around several common key roles (Strüker et al. 2021, Lim 2020, Kubach et al. 2020, W3C 2024).[16]

The key technical building blocks are *digital wallets* (generally to be held on the user's smartphone or other devices), *verifiable credentials* (VCs) and *decentralised identifiers* (DIDs). World Wide Web Consortium (W3C) standards exist for VCs (draft recommendation) and DIDs (W3C 2022, 2024; Strüker et al. 2021; Richter and Anke 2021).

Verifiable credentials (VCs) are tamper-proof digital certificates that are issued and cryptographically signed by a trusted party (e.g. a university issuing a digital degree certificate, an online service provider issuing a credential to authenticate a registered user). VCs, in effect, contain attributes about a user (e.g. name, university degree class). Users store the VCs issued to them in the *digital wallet* on their smartphone or other device (Kubach et al. 2020, W3C 2024).[17]

A major strength of VCs is that – provided their issuer is trusted – the information contained in them can be accepted as true because they are tamper-proof and cryptographically signed by the issuer. Their validity can thus be proven automatically, with no need to contact the issuer to confirm a credential. This offers some – arguably mostly minor – privacy benefits to the user (see below), but also substantial efficiency gains for users and service providers, as the verification of identity attributes no longer requires lengthy "manual" communication between service provider and issuer (Kubach et al. 2020, Richter and Anke 2021, W3C 2024).

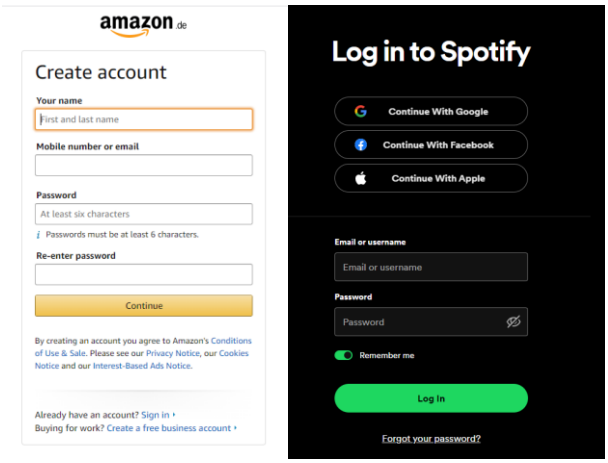

Figure 1. Registration interface in a centralised identity system (l); Log-in interface with SSO Identities (r)

A further strength of VCs is that they can be exchanged through encrypted peer-to-peer channels. For this, *Decentralised Identifiers* (DIDs) are used. DIDs identify parties to an exchange to each other (e.g. user and service provider, who exchange information/attributes). They allow the two parties to recognise each other. Importantly, the DIDs allow for this exchange to take place via an encrypted peer-to-peer channel, that can be observed only by the parties to the exchange (Richter and Anke 2021).[18] It is common to create a unique, temporary DID channel for each interaction with each service provider.

The communication between user and service provider in an SSI system using DIDs is thus fundamentally different to that in an SSO system. With SSO, the communication is tripartite and intermediated by the SSO provider, who can observe the user and, in theory, even block her from using her identity and accessing the service. With SSI, using a DID channel, the communication between user and service provider is strictly bilateral. No third party can observe or interfere with the communication. (It is however possible for service providers to collude with each other and/or VC issuers *after* the communication, to further profile and track users [W3C 2024].) Thus, the key roles in the SSI ecosystem are:

- the *issuer* of credentials (VCs)
- the *user* (sometimes called "holder"), who receives VCs from the issue and stores them in her digital wallet
- the *service provider* (often called "relying party" or "verifier")

When she accesses a service or engages in some other transaction with the service provider, the *user* presents VCs to the *service provider* via a DID channel. The *service provider* then "verifies" the VCs and "relies on" the *issuer* for their trustworthiness.[19]

Note that service providers can simultaneously also be issuers. For example, in an SSI ecosystem, signing up to an online service provider (e.g. creating an account with an online bank) could involve presenting the service provider (the bank) with a state-issued VC of one's identity card to prove one's identity, whereupon the bank issues one with a further VC, with which one can authenticate (log in) to one's new account. When one next logs in, one then just presents this VC.

The Chimera of Control

SSI advocates point to three mechanisms through which SSI supposedly gives users control over their data and identity. Firstly, users must consent to any disclosure of their VCs. This is architecturally hardwired into SSI, as only the users control their digital wallets with the VCs. Secondly, identity providers are disintermediated. There is no SSO or other identity provider, who stands between the user and the service provider and can revoke the user's access to and use of her identity and attributes. Rather, these are all contained in the digital wallet and are directly presented by the user to the service provider, via peer-to-peer DID channels. By the same token, there is no SSO or other identity provider who can directly monitor the user's behaviour. Likewise, because the VCs' authenticity is verified automatically by the service provider, without direct involvement of the issuer, the issuer too is unable to monitor the user's behaviour (unless issuers and service providers collude to do so.)

Thirdly, it is in principle possible to equip SSI systems with additional features to enhance user privacy; especially Zero Knowledge Proofs (ZKPs) and Wallet Histories (Hempel and Anke 2023, W3C 2024). ZKPs enable attributes about an entity to be proven without disclosing the underlying information (e.g. that a user is older than 18, but not her actual age). Thus, the amount of data that needs to be provided about a user can be minimised. Wallet Histories give users a more complete overview of what data (VCs) they have disclosed to which service providers, for what purposes. That makes it easier for users to exercise GDPR rights, e.g. to request that service providers delete their data.

All three mechanisms provide users with some potential influence over their data and, in this sense, their identity (if "identity" is treated in objectivist terms: none offer control over identity-as-relationship). Unfortunately, this added influence is far from the kind of "sovereign control" that the rhetoric of SSI advocates frequently implies. On the contrary, at best SSI provides users with some technical aids to help them operationalise GDPR rights and via ZKPs, the GDPR's data minimisation requirement.

The fundamental reason for this lies in the highly unequal political-economic (power) relationship between users and service providers in the digital economy, which SSI is unable to address. This is exemplified by the problem of consent.

Consent and Control over the Information Contained in VCs

As noted, in an SSI ecosystem, users store their data as VCs in their digital wallets. Service providers must ask users for permission (consent) to access and process these. Users can then decide whether they wish to grant service providers this consent. SSI advocates cite this as a key instance of users exercising "control" over their data (e.g. Schardong and Custódio 2022). Superficially, this is indeed the case – users are technically free to refuse consent.

But there are three problems with this. For one, this is hardly very different to how registration processes *already* work in centralised or federated identity systems. Recall the example of onboarding to Amazon (or most other online service providers): as part of the onboarding process, Amazon (the online service provider) requests various pieces of user data and spells out – in lengthy legal documents[20] – under what terms and conditions it will store and process this; terms and conditions the user must consent to in order to use the service. This is no different if she uses an SSI system to onboard and provides her data to Amazon via VCs.[21]

Secondly, while VCs remain in some sense in the user's possession, the *information they contain* (i.e., the user's data) do not. Rather, when the user presents her VCs to the service provider, the service provider reads out the information (data) contained in the VCs. Provided the user "consents", there is no technical barrier to stop the service from storing and further processing these data, including tracking the user across external data and devices, and in cooperation with other third parties.[22] Once the information is entered into the service provider's systems, it is beyond the user's control.

Thirdly, while, at least in Europe, the user does need to consent, as indicated above, consent is only meaningful if the user has real alternatives and a full understanding of what they are consenting to. Only then can the act of consent represent the exercise of some form of genuine "control" or self-determination. In the case of Amazon, most goods sold there can likely be obtained through other online or offline sellers. In this sense, the user at least has

alternatives. But it is likely that most alternative online sellers would present users with comparable or even more invasive data requests, couched in equally long and complex legal documents.[23] The alternatives may thus present little real choice. Conversely, making purchases offline requires the user to pay a steep opportunity cost (time, effort).

Making online purchases may be a trivial example, as offline alternatives exist and access to Amazon or other e-commerce sites is rarely existential. But access to other services is more so. Take banking, social networks or messenger services. It is all but impossible to participate in a modern economy without a bank account. Given the central role of social networks and messenger services to communication flows today, it is difficult in many situations to refuse their use, if one wants to participate in society. Any theoretical "choice" users may have about whether to consent to their data requests is thus largely chimerical. To "consent" is less the sign of users exercising "control" than facing take-it-or-leave it choices where "leave it" is not an option. SSI does not change this.

Disintermediation of (some) Identity Providers

SSI does disintermediate SSO providers. This is a net gain for user privacy and user data "control", in as far as it reduces the number of parties monitoring user behaviour and the number of parties to whose data collection users must "consent" to. Likewise, it aims to remove certificate issuers from the verification process. However, these privacy gains are arguably minor: Google and Facebook, the main SSO providers, have many other means to surveil users (Christl and Spiekermann 2016), and users must still consent to data processing by service providers. While the *aim* is to remove certificate issuers from the verification process, this is ultimately up to the actors in the ecosystem: there are few technical barriers to stop service providers and issuers colluding to track users (though the W3C standard appeals to them not to do so).

It is unclear whether SSI would also disintermediate *centralised* identity providers, though this seems unlikely. Centralised identity providers are usually also service providers, and issue an identity as part of, and in order to, provide the service. They would likely do this also in an SSI ecosystem. For instance, Amazon would presumably still want its users to create accounts with unique identities for use of its services. While no SSO-type intermediary would exist to potentially block users from using an identity, service providers and certificate issuers remain free to revoke identity credentials they have issued, e.g. if users violate terms of service.

More fundamentally, as discussed, the *value* of an identity/identity attribute depends on it being recognised by others. Generally, the most valuable identities and attributes are those issued by powerful states or institutions that command unique resources (e.g. famous universities with degree-granting power). These identities/attributes offer their holder the greatest panoply of rights and benefits. SSI does not change this. While users may be able to use some SSI systems to issue themselves with their own identity certificate, such a self-issued identity certificate is likely without value. On the contrary, to access most valuable services, SSI users are all but certain to remain dependent on identity credentials (VCs) issued by states and other powerful institutions.

Wallet Histories and Zero Knowledge Proofs

Wallet Histories and ZKPs do offer users modest gains in data control and privacy – provided service providers act on user requests enabled by Histories (e.g. to delete data) and accept ZKPs rather than demanding the underlying data. But nothing about SSI (or Histories and ZKPs) forces service providers to do so. What *can* force service providers to do so is not technology, but law – for instance the GDPR data subject rights, whose exercise Wallet Histories can facilitate, and the GDPR's data minimisation principle (Art. 5(1)(d)) and privacy by design and default stipulation (Art. 25), which could be read as *mandating* ZKPs once these are technologically mature.

In summary, the three mechanisms by themselves do not significantly increase users' control over their data and their identity-as-thing, while they cannot in any way increase users' power or control over the identity relations that generate actual value from identity (identity-as-relationship/status). Wallet Histories and ZKPs arguably can somewhat increase users' privacy and control, but this depends on institutions (e.g., laws) actually forcing their use. In Europe, the GDPR may ultimately do this. That raises the question of what effects SSI may have in environments where institutions such as the GDPR do not exist.

SSI as Disclosure Machine?

A key benefit that SSI systems offer users is the digital wallet and the ability to store all their identity credentials and attributes as VCs in one easily accessible place. This allows users to conduct digital transactions faster and with less friction than with existing systems, where credentials continue to be stored over a wide range of systems (desktop, smartphone, paper box files) and in many different formats (pdfs, jpegs, hard copy,…) , often distributed over multiple entities (user, employer, health insurance, …). Moreover, unlike the pdfs and jpegs that users often still rely on today, VCs are hard to falsify and can be quickly and easily verified.

This is a key reason why business interests support SSI. It promises to reduce costs and increase service consumption as friction is reduced, and to provide more reliable data about users, VCs being tamper-proof and verifiable (Anke and Hempel 2023).

But absent legal safeguards like the GDPR, these characteristics also threaten to turn SSI into a disclosure machine. Faced with wallets brimming with interesting data that can be made available in seconds via a few clicks, businesses and state institutions will be sorely tempted to demand all manner of additional data disclosure as a condition of service access, well beyond what is strictly necessary to provide the service. Facing take-it-or-leave-it choices about service access, users will likely find it hard to refuse. We call this "data extortion". With terms of service commonly packed into pages of dense legalese, users will often struggle to even understand what is being demanded of them. Far from securing user privacy and data control, SSI would thus make users *more* transparent and *reduce* their control over their data.

In Europe, the GDPR's data minimisation principle, among other stipulations, provides some safeguards against this. But in many other contexts institutions like the GDPR are

absent. SSI's potential to turn into a disclosure machine under these circumstances is underscored by Wang and De Filippi's (2020) description of the UN World Food Program's (WFP) "Building Blocks" program. As they describe it, Building Blocks sought to harness blockchain, biometric recognition and public key infrastructure for disbursal and management of Syrian refugees' humanitarian assistance entitlements (food, health, cash, education etc.) in Jordan. The system conforms broadly to the SSI idea, albeit with some architectural adjustments to fit the circumstances of a refugee camp. For instance, it did not require users (refugees) to possess smartphones or similar devices. Rather, each refugee received a unique identifier anchored to their biometric data plus associated public/private keys, and an individual account or "blockchain wallet" (Wang and De Filippi 2020) on the chain, in which information about their entitlements and transactions conducted was stored.[24] The initial aim of the system was to streamline cash disbursal to refugees and save banking fees (Microsoft Sway n.d.). However, as the account in Wang and De Filippi (2020) and statements from the WFP make clear, operators quickly recognised the system's potential to give them a much more systematic and comprehensive, "unified" view of the refugees: the ~106,000 refugees in Jordan were served by another 45 different NGOs and aid agencies aside from the WFP, each with their own data systems. This led to a "fragmented view of the people served", duplicated efforts and inequities (Wang and De Filippi 2020). A solution was seen in collecting all entitlements as well as other relevant information (e.g. status as a nursing mother) in the refugees' blockchain wallets, thus providing the agencies with a "unified view" of the refugees, to ensure equity of provisions and avoid duplications. In other words, the potential of digital wallets to render the refugees highly transparent and the functional benefits this could provide to operators were quickly recognised, and steps taken to explore implementation options.

It is unclear to what extent other aid providers, beyond the WFP, were ultimately given access to Building Blocks and refugee entitlements collected in such a comprehensive way. It should also be noted that important measures were implemented in Building Blocks to avoid disclosing excessive information to actors within the network.[25] The point is not that Building Blocks was "evil" or that rendering refugees more transparent to aid agencies is unjustifiable or would lead to disaster. Ensuring equity and *adequacy* of aid provision is often likely to be more important than adhering to a privacy absolutism. Rather, the case illustrates how the capability of the digital wallets, that are at the heart of SSI, to serve as collection point for all of an individual's relevant identity information immediately leads to covetousness for ever more of this data among service providers and other digital actors. As discussed above, left to themselves, users will rarely if ever be in a position to resist such demands.

Interim Conclusion: "Control" in SSI Systems

We thus conclude that the claim made by SSI advocates that SSI gives users meaningful control over their (i) data and (ii) their identity, is factually wrong. Unless additional functions (Wallet Histories and ZKPs) are included, SSI solutions do not provide any significant increase in user's control "over their data" than existing solutions. Even with Wallet Histories and ZKPs, SSI can unfold its limited increase in data control only through the interplay with powerful supportive legal structures. Absent these, SSI risks turning into a

"disclosure machine" wherein users become *more* transparent and more vulnerable to "data extortion" by service providers than they often are already. The reason for this is that users' lack of control over their data derives from structural power imbalances that SSI neither can nor tries to fix.

The claim that SSI gives users control "over their identity" is harder to evaluate, as it is less clear what it means. If "identity" refers to the underlying data (attributes, VCs), then the above applies. If "identity" refers to users' social, legal-political or economic status (identity as relationship), then too the claims for SSI necessarily fall short. The reason is again its inability to alter the power imbalances in the relationship between users, issuers of credential and grantors of benefits.

PART TWO: USER PERCEPTIONS

Method

To explore users' views of SSI solutions we included several pertinent questions in a larger online survey about the use and adoption of digital identity technologies, conducted as part of the IMPULSE project.[26] The survey ran from February to June 2023. The survey link was initially disseminated through the personal and professional networks of the researchers and staff members from the IMPULSE consortium's 15 partner institutions in their countries (Germany, Spain, Italy, Denmark, Iceland, Bulgaria, Finland and France). Respondents were asked to pass the survey on further in their own personal networks (convenience sampling). This dissemination method was chosen as financial constraints prevented the use of e.g. a survey company. To incentivise participation, a donation of €2 to charitable organisations was promised per completed survey, up to a total of €500.

There were 740 valid responses (205 to the German-language instrument, 192 to the Spanish, 116 to the Italian; and 62, 60, 42, 39 and 24 to the Danish, Icelandic, Bulgarian, Finnish and French, respectively). Respondents' age ranged from 18 to 82 years (average 43.4; median 41) and were disproportionately well-educated (79% had or were currently in university education) and affluent (by income, 53% belonged to the top-20% of income earners; 16% to the top 60-80%), and 93% white. Conversely, the gender split was almost exactly 50-50 (49.5% male, 49.7% female, rest diverse or n.a.). 57.4% of respondents live in small or medium-sized towns; 25.5% in major cities, 17% in villages. Evidently, the survey population is not representative of the general population, as was to be expected given the dissemination strategy. The implications thereof for the external validity of the following analysis are discussed in closing.

The main objective of the survey was to understand user acceptance decisions regarding the IMPULSE digital identity system, an SSI-type digital identity system developed in the eponymous project. To this end, demographic, attitudinal and experiential data were collected (among others: age, gender, education, income; privacy concerns, technology openness; experience with digital identities, authentication technology preferences; willingness to use IMPULSE, reasons for non-use, and perceptions of the system). The full survey instrument is provided in the Appendix. The survey items were based on the extant literature and theories about user acceptance of digital technologies and identity systems. A full analysis of the

determinants of user acceptance is presented in Martin and Metzger (under review). Of interest here is the information that the survey provides about whether users are likely to believe that SSI systems give them "control" over their data, if such a system is described to them (RQ 1), and if so, how important this belief is for driving adoption (RQ 2).

To collect data on this, survey respondents were shown a five and a half minute long animated video explaining IMPULSE (described below), and then asked whether they "would use IMPULSE instead of the digital identity (log-in) systems [they] currently use (like username/password, smartcard, PIN, etc.), if IMPULSE were available?" Answers were collected on a Likert scale running from 1 ("certainly not") to 5 ("certainly yes").

Several questions later, respondents were given 18 different words and phrases and asked to choose all that "you feel describe IMPULSE". These included positive and negative characterisations (e.g., "convenient", "saves time", "complicated", "surveillance"). Of interest here are the following three: "IMPULSE gives me control over my data", "With IMPULSE, I can decide who gets my data", and "privacy-friendly". These items were interspersed in the middle and towards the end of the entire set of descriptors, with various other descriptors in between.

Finally, again two questions later, they were given six statements describing different aspects of "having control over one's data" and then asked to choose the three most important ones in their view.[27] The following statements were presented to them, in the order below:

- Online service providers have to ask for my consent before collecting or using my data.
- Online service providers must provide a short, easy-to-understand privacy policy explaining how they use my data.
- Online service providers cannot demand more data from me than necessary to make the service work.
- Online service providers cannot refuse me their service unless I allow them to use my data for advertising.
- Online service providers cannot use website lay-out and other tricks that manipulate me to give them extra data or data-use permissions.
- Online service providers must delete my data if I ask them to.

The logic behind these different questions and their order of appearance was as follows. Asking whether respondents would switch to IMPULSE is self-explanatory. We formulated the question so as to create a direct comparison between IMPULSE and respondents' current digital identity systems. This creates a harder test of IMPULSE true adoption potential, since this primes respondents to think about pros/cons compared to their current system.

The descriptors "IMPULSE gives me control over my data" and "With IMPULSE, I can decide who gets my data" present respondents with the standard claim SSI advocates make about these systems, formulated in two slightly different ways. The first phrase is more abstract than the second and arguably rhetorically slightly stronger (IMPULSE *gives control*), but semantically they are near-identical: to have control over one's data is to get to decide

who gets it, and vice-versa. The more general descriptor "privacy-friendly" gives respondents an alternative item to tick if they want to comment positively about the system's privacy qualities, thus reducing the risk that the two "data control" items get "abused" for general commentary on privacy. To avoid these three items priming respondents to assume that IMPULSE is particularly privacy friendly, the negative descriptors "surveillance", "creepy", "weird" and "dangerous" were also shown. The description of the IMPULSE system presented to respondents in the video was careful to explain the data flows in the system but not make any positive or negative statement about its privacy qualities or "data control".

Finally, the dimensions of data control, from which respondents were asked to pick the three most important, include both the relatively weak and formalistic requirements to ask users for consent and provide a privacy policy, and more substantive controls: deletion of data upon request, protection from manipulation, use of data for a purpose unrelated to service provision, i.e. advertising, and data extortion: demanding more data than necessary for service provision – one of the key threats SSI systems pose (cf. Part I). Of interest here is whether respondents associate data control primarily with the weaker and more formalistic dimensions consent and privacy policy (which SSI advocates regularly reference as means by which SSI operationalises data control for users), or whether they see the other, more substantive dimensions – that SSI does little to operationalise and can even actively threaten ("disclosure machine") – as critical. The data control-dimensions question was asked last, to avoid priming respondents when they answered the foregoing questions.

The IMPULSE System

IMPULSE consists of three core components: A smartphone application for the user, an enterprise module for the online service provider (installed in her IT systems), and a blockchain[28]. As a typical SSI system, IMPULSE uses decentralised identifiers (DIDs) and blockchain for communication between user and service provider; verifiable credentials (VCs) to represent the user's data and identity, and a digital wallet in the app on the user's smartphone to store the VCs in. Authentication works via facial recognition, but this is incidental.[29]

The process by which the system works and the user onboards to an online service (e.g. an online bank, a state agency, or an e-commerce site) with IMPULSE is shown in Figure 2: The service provider stores his DID and trusted issuer information ("verification information") on the blockchain (Step 0 in Figure 2 left). When the user accesses the online service (e.g. via a "Sign Up with IMPULSE"-link), the IMPULSE app accesses this verification information to check that the service provider has been registered as a trusted party. This happens automatically in the background.

The first step on the user onboarding journey with IMPULSE is that she is presented with the service provider's data use/privacy policy. She has to consent to this to be able to onboard to and use the online service. This done, she is asked to take a photo of the front and back of her state ID card or passport, and a selfie (Step 1). These are uploaded to the IMPULSE enterprise module installed in the service provider's IT system via an encrypted p2p DID channel. Prior to upload, a biometric module integrated in the IMPULSE app creates a biometric profile of the user from the selfie and stores this profile in the user's

smartphone. This profile is used when she authenticates to the online service next time. The profile is *not* shared with the enterprise module. The enterprise module (on the online service provider side) of IMPULSE then uses artificial intelligence to check that the selfie and the user's picture on her ID card match and verifies the authenticity of the ID documents. This user verification can be fully automated, but for compliance with EU eIDAS regulation, IMPULSE foresees a human in the loop (a worker on the online service provider side who manually confirms that the photos match). Next, data that the online service requires are automatically extracted from the ID card photos (e.g. name, data of birth, address). If additional data that is *not* contained on the ID card is needed (e.g. bank details), then the user enters these manually. The data are encoded in the verifiable credential that the service provider creates for the user (to be read out later by the service provider when the VC is presented during authentication) and/or stored directly by the service provider in their systems (Step 2). With verification of the user completed, all photos are erased and the service provider creates the VC for the user (Step 3). The VC is sent to the user, to be stored in the IMPULSE app digital wallet on her smartphone (Step 4). The user is now onboarded to the online service provider (Step 5).

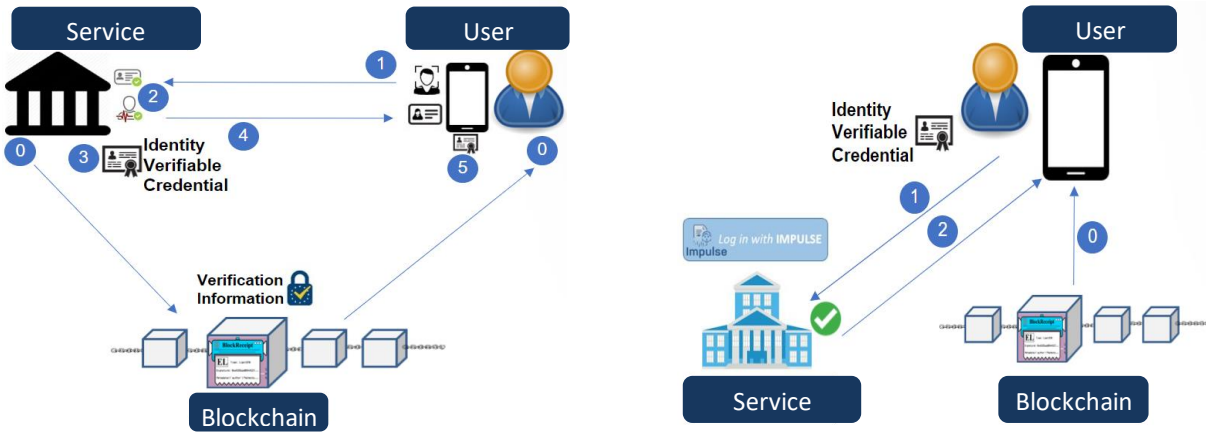

Figure 2. User onboarding to IMPULSE (left) and authentication after completed onboarding (right)

When she next wishes to authenticate to the service to use it, she goes to the service provider's webpage, chooses "log in with IMPULSE", and the IMPULSE app on her smartphone again checks the service provider's verification information from the blockchain (Step 0 in Figure 2 right). To access the verifiable credential that she will present to the service for authentication, she takes a selfie, which is checked via facial recognition against the biometric profile stored on her Smartphone. She can now present the VC to the service provider via a DID channel (Step 1). The service provider "verifies" the VC and authenticates the user (Step 2). She can now use the service. Data required by the service provider is read out from the VC or retrieved from service provider's IT systems. If additional data that the user has not yet provided to service provider subsequently becomes necessary, she can supply this in several ways. If she already has the data in the form of a further VC, perhaps issued to her by a different entity (e.g. a VC of her university diploma), she can simply provide this VC to the service provider, for him to read and extract the information from. Alternatively, if she

does not yet have the data in VC form, she can enter it manually (or in some other form, e.g. as a JPEG) to the service provider. Depending on the context, the service provider may again turn this into a VC for her to store in her digital wallet – and potentially share with other service providers. (She could of course refuse to provide the additional data, at the cost of foregoing the feature that it is needed for or even giving up using this service provider entirely, if he makes the new data request a precondition for further use.)

While IMPULSE's use of facial and document recognition is distinctive, the basic architecture and data flows are typical of SSI systems: Users hold their data in the form of VCs – issued to them by service providers or other third parties – in their digital wallet, and provide the VCs to service providers who read and/or extract data from them in the context of service provision via DID channels. We can therefore treat survey respondents' reactions to IMPULSE as at least indicative for how users might view other SSI systems, too.

Such a DID/VC/digital wallet-based system provides the user with greater convenience and security compared to many existing processes. Important data (e.g. one's legal identity, as attested by one's state ID card) can be easily and securely provided to service providers and other entities. The data is in a format that can be very quickly and automatically verified as correct. With IMPULSE, the use of facial recognition in place of passwords or PINs provides additional convenience and security. Together with the document recognition function, this allows even onboarding to sensitive services – which conventionally would require in-person or video-chat sign up – to be done swiftly and conveniently from home.

As discussed in Part I, what such a system does *not* however do, is to provide users with meaningful "control" over their data. But would users recognise that too? To understand this, in the survey, we described the onboarding and authentication processes and basic data flows in IMPULSE to survey respondents by means of an animated video, narrated in the respondents' languages (Spanish, Bulgarian, German etc.). Online banking was used as an illustrative example use case.[30]

The video explained that to use internet services like online banking one needed a "digital identity", often a username/password and associated data like one's address, and that one usually created this digital identity when signing up for the service. It noted that people often chose simple, insecure passwords, and introduced IMPULSE as a novel smartphone-based digital identity system that instead used facial recognition. It outlined the main steps in the onboarding and authentication journeys: accessing the service provider's website, taking the photos of ID card and selfie, AI-based analysis of the photos by IMPULSE to verify the user and create the verifiable credential (called "digital identity" in the film to avoid tech jargon), deletion of the photos and secure, encrypted storage of the VC ("digital identity") on the user's smartphone. The film was careful to avoid broaching the topic of "controlling one's own data". It noted that for the service provider to make the service (e.g. banking) available, the user might have to provide data stored on their phone (i.e. VCs) or additional data, and noted that "the service provider may sometimes keep this data, if you agree, or if they have to for legal or technical reasons." The issue of data extortion discussed above (having to provide more data than necessary for the service, or be refused service) was not raised.

Results for Research Question 1: User Perceptions of "Control"

Figure 3 shows the percentages of respondents who (1) stated that they were "concerned" or "very concerned" about online privacy[31], (2) who chose "privacy friendly" as a description of IMPULSE, (3) who chose the descriptor "IMPULSE gives me control over my data", (4) who chose the descriptor "with IMPULSE I can decide who gets my data", and (5) who chose the descriptor "convenient" for IMPULSE. Of all descriptors, "convenient" was the one most frequently chosen.

As we can see, the sample population was quite concerned about online privacy with 60.7% choosing 4 or 5 on the Likert scale. But only 28.5% believed IMPULSE was privacy friendly[32]. Even fewer believed that the system would "give [them] control over their data" (13.2%) or felt that "with IMPULSE [they] could decide who gets [their] data" (14.2%). By contrast, over 37% thought it was "convenient".

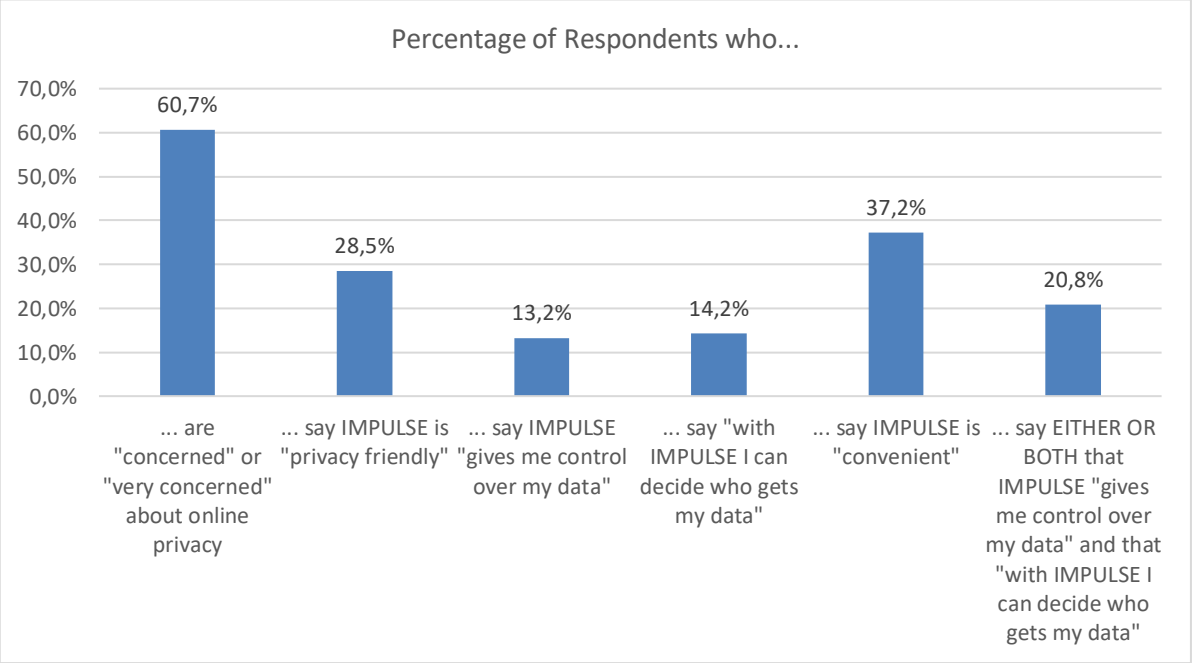

Figure 3. User perceptions of IMPULSE

The two descriptors, "gives me control" and "I can decide who gets my data", are semantically near-identical. Presumably they capture the same underlying phenomenon/belief structure, and respondents who ticked one ought logically to tick the other, too. In practice, though, only ~32% of the respondents who chose one of the two descriptors also chose the other (Figure 4). The rest chose only one of the two. If we add these two groups together, the share of respondents who seem to think that IMPULSE in some way gives them control or decision-making capability over their data rises to 20.8% of the total sample population. (Figure 3). However, the fact that nearly 70% of the respondents who picked either of these two semantically identical descriptors failed to also pick the other one, suggests that most

struggled with the concept of "having control"/"getting to decide" over their data. Indeed, only 6.6% of the total sample population picked both.

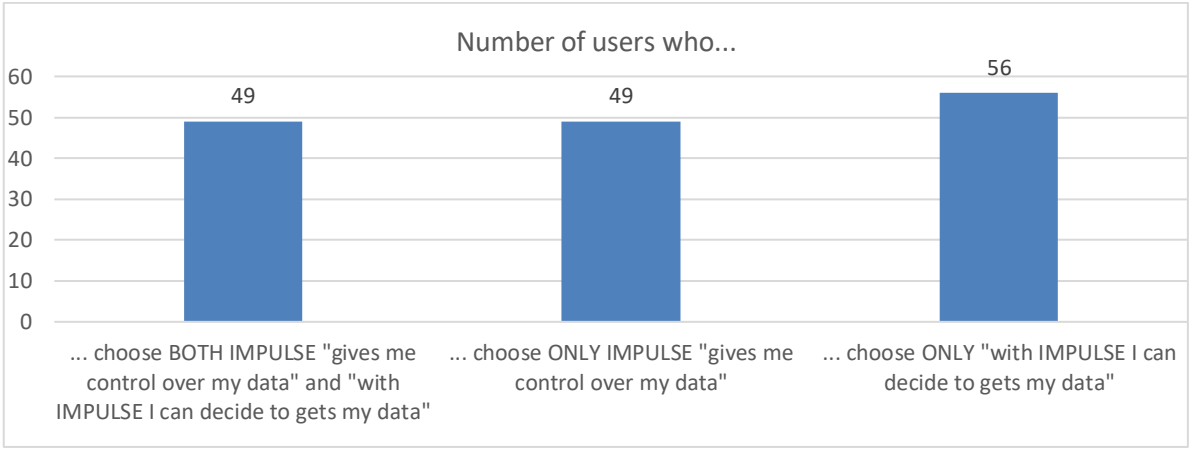

Figure 4. User choices of "control"/"decide"-descriptors

This is also supported by how respondents answered the question about different dimensions of having "control over data" (Figure 5). Three items – that service providers must ask for consent, cannot demand more data than necessary to make the service work (data extortion), and must delete data upon request – are chosen as among the "most important" by relatively large shares of respondents, viz. 69%, 66% and 59%. Conversely, only 31% to 37% choose any of the other three items (no manipulation to get data, privacy policy, no use of data for advertising as a condition of service access).

Yet only 22% chose *all three* of the "popular" items (consent, no data extortion, deletion upon request) (Figure 5). The other 18 possible three-item combinations (e.g. consent, no data extortion, no manipulation, etc.) are each chosen by just ~3% to ~11% of respondents (not shown here). This suggests that while some items clearly resonate with far more respondents than others, overall the respondents struggle to form a systematic and encompassing concept of "having control over their data". In turn, this suggests that even those respondents who selected either or both of the "control over my data"/"get to decide who gets my data"-descriptors, likely did *not* have a well-developed, rigorous concept of what such control would actually entail or require. On the contrary, rather strikingly 70.4% of the respondents who selected the "control"-descriptor, and 63.8% of those who chose the "decide"-descriptor, *also* chose "service providers cannot demand more data from me than necessary" as one of their three most important dimensions of data control. But as we have seen, this is precisely *not* ensured by IMPULSE, or any other SSI system.

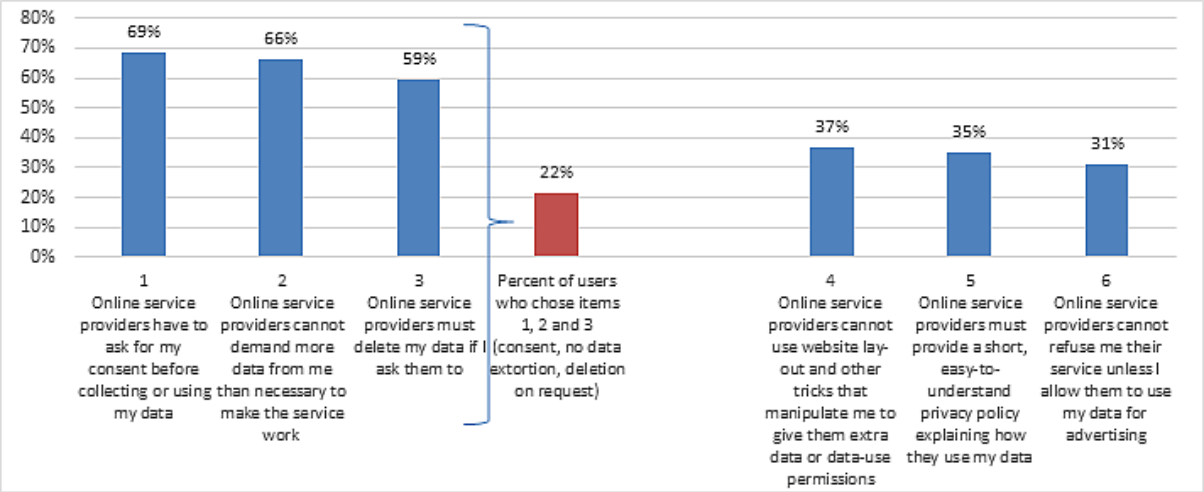

Figure 5. Percentage of users who regard selected dimensions of "data control" as among the 3 "most important" dimensions

This raises the question of who the 20.8% of respondents are who seem to believe that IMPULSE gives them "control over their data". Figure 6 compares them to the entire survey (sample) population on several demographic variables. What stands out is their *lack* of differentiation. Whether in regard to age, gender distribution, income levels, place of abode, technology openness and privacy concern, the subpopulation of respondents who chose either the "control"- or "decide"-descriptor is virtually indistinguishable from the general population: they are on average a little over 40 years old[33], about 50-50 male/female, highly educated with ~80% having completed or currently in university, and earn above-average incomes. Over half live in small towns; about a quarter each in major cities or villages. Most are open or very open to new technology, but also concerned or very concerned about online privacy. There is more national variation, with respondents from Germany, Denmark and Spain ticking the two descriptors at about the rate of the sample population average, Italians and Icelandics somewhat less, and responses from Finland and France swinging wildly (likely also due to their smaller sample sizes) (data shown in Appendix). However, lacking strong theoretical reasons to expect national divergences here, we put this down to random variation.

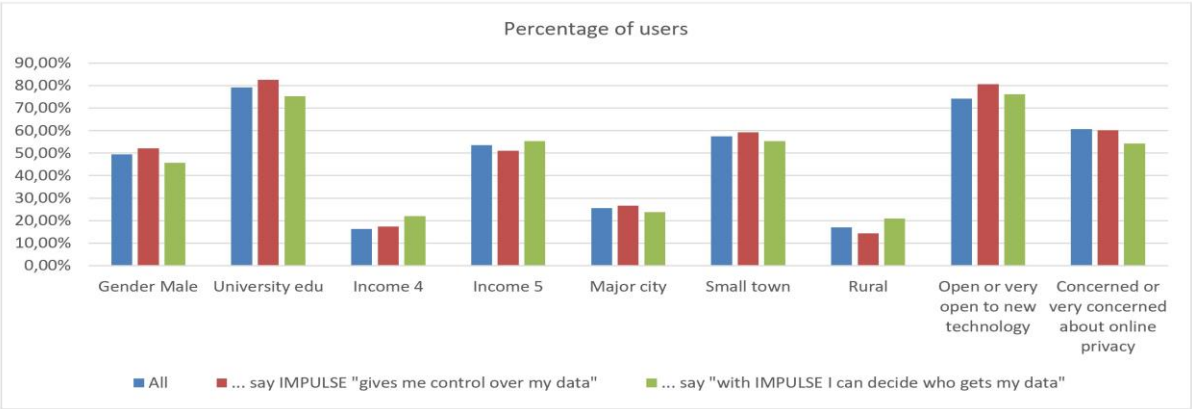

Figure 6. Demographic and attitudinal characteristics of different respondent (sub) populations

Interim Conclusion: Findings related to Research Question 1

Regarding RQ 1 – whether users, if given a description of how an SSI system works, are likely to conclude that it will put them in control of their data – we thus conclude: Most users are *not* likely to conclude that SSI will put them in control of their data. In our survey, at a maximum 20.8% of respondents seem to have concluded something along these lines about IMPULSE. Only 6.6% seem to have concluded that IMPULSE gave them control of their data, and had a sufficiently rigorous understanding of this notion to tick *both* descriptors. (For further discussion of external validity see below.)

Furthermore, the survey suggests that users are unlikely to have a systematic, broadly shared understandings of what having "control over their data" means, and may struggle to apply what notion they do have in this regard, to assessing SSI solutions in a rigorous fashion. This is unsurprising, given the abstract nature of the concept and the sophisticated understanding of digital technology and ecosystems required to apply it rigorously. That in turn however implies that users may be quite suggestible: as they lack a clear idea of what "control over their data" means, it could be fairly easy to persuade them, at least temporarily, that SSI (or some other technology) gives them this. I.e. while the number of users who by themselves are likely to conclude that an SSI solution would offer them "control" is low, a professional marketing campaign may well be able to change that dramatically, at least temporarily.

Thirdly, no specific demographic or attitudinal characteristics distinguishing those who seem prone to concluding that SSI gives them "control over their data" could be identified.

Results for Research Question 2: Effect on Adoption

To understand whether the belief that an SSI solution provides "control over data" materially affects adoption decisions, we conducted Ordinary Least Squares regression analysis using the R software package.

The results are shown in Table 1. The *dependent variable* in all models was respondents' self-reported likelihood of switching to the IMPULSE system, should the system become available. The item was measured on a Likert scale from 1 to 5 (from "certainly not" to "certainly yes").

The explanatory variables of interest here are:

- *ControlPerception:* an ordinal variable with values 0, 1, 2, that captures whether respondents ticked none, one or both of the "control over/get to decide who gets my data"-descriptors.
- *ControlDescriptor:* a dummy variable with value 1 if respondents ticked the "control over my data"-descriptor, and value 0 if not.
- *DecisionDescriptor:* a dummy variable with value 1 if respondents ticked the "get to decide who gets my data"-descriptor, and value 0 if not.

The following control variables were included in different models:

- *Age*: a continuous variable running from 18 to 82, capturing the respondents' age.

- *Gender_Male:* a dummy variable with value 1 if the respondent is female, and 2 if male (Respondents who reported their gender as "diverse" were excluded, due to their very small number).
- Education: a categorical variable with value 1 if the respondent has completed high school (but not attended university), and value 2 if the respondent has completed or is attending university. The value 0 is given if the respondent has not completed high school, and is the reference category. R reports the coefficients for each value that the variable takes separately in the regression table (except the reference category). Thus the table includes *Edu_HighSchool* (when the education variable has the value 1) and *Edu_University* (educational variable value of 2).
- Income*:* a categorical variable with values 1 to 5, corresponding to the income quintile (based on EuroStat data) that the respondent's self-reported income is in. (I.e. value = 2 if the respondent's income situates them in the second quintile; value = 3 for the third income quintile, etc.). The reference category is the first quintile. R again reports the coefficients for each value that the variable takes on separately (except for the reference category), viz. *Income_Q2* for second quintile, *Income_Q3* for third quintile, etc.
- Ethnicity: a categorical variable with value = 1 if the respondent self-reported to be "white" (reference category), value = 2 if the respondent self-reported to belong to an ethnic minority, and = 3 if he or she refused to report their ethnic identity. The reference category is 1; R reports the coefficients for Ethnicity = 2 (*Ethnic_Minority*) and = 3 (*Ethnicity_Refuse*) separately.
- *TechOpenness:* an ordinal variable running from 1 to 5, capturing the respondent's self-reported enjoyment of new technology.[34]
- *PrivacyConcern:* an ordinal variable running from 1 to 5, capturing the respondent's self-reported level of concern over their online privacy
- *Usability:* an ordinal variable running from 0 to 5, with 1 point added for each of the descriptors "convenient", "easy to use", "makes signing up for services easier", "makes logging in easier" that the respondent ticked.
- *Country*: a categorical variable with country coding for Bulgaria (reference category), Denmark, Finland, France, Germany, Iceland, Italy, Spain.
- An interaction term between the *country* variable and *PrivacyConcerns*.

In further models we also added interaction terms between the country variable and income quintiles, and further controls for digital skills and place of abode (rural village, major city). For simplicity of presentation these are not included here as they were consistently not significant and had no impact on the significance or effect size of the three "data control"-variables that are of interest here. A detailed analysis of all factors determining adoption decisions is in preparation (Martin and Metzger u.r.). Here we concentrate on the impact of the three "data control"-variables.

Model (1) in Table 1 includes all control variables except for Country, and the Country-*PrivacyConcerns* interaction. The *ControlDescriptor* and *DecisionDescriptor* are both significant at the $p<.001$ level, with a positive sign and similar coefficient sizes, a pattern that continues in the following models. This indicates that the two variables are indeed capturing

the same underlying phenomenon/belief structure in respondents. Significant at the p<.001 level, too, are *Usability* and *TechOpenness*. *PrivacyConcerns* is negative but *not* significant. The other control variables are likewise not or only weakly significant, with the exception of *EthnicityRefuse*.[36] (For further discussion see Martin and Metzger u.r.). In Model (2) we add the Country variable. *PrivacyConcerns* now becomes significant at the p<.001, with a negative sign. The other variables remain largely unchanged – including *ControlDescriptor* and *DecisionDescriptor*. The Country controls are all negatively signed and mostly significant at the p<.001 level.[37]

Model (3) includes the Country-*PrivacyConcerns* interaction. This turns *PrivacyConcerns* positive (!) albeit robbing it of significance. *ControlDescriptor* and *DecisionDescriptor* remain significant at the p<.001 level (as do *Usability* and *TechOpenness*), with similar coefficient sizes as before. In Model (4) we use *ControlPerception* instead of *ControlDescriptor* and *DecisionDescriptor*; it too is positive at the p<.001 level and coefficient size is similar to that of the two Descriptor variables in the previous models.

In summary, the "data control"-variables are significant at the p<.001 level across all models, with a consistently positive effect. Notably this is robust to the inclusion of country dummies. While these cause the significance, coefficient size and, with interaction effects, even direction of *PrivacyConcerns* to bounce around considerably; these remain largely unchanged for the "data control"-variables. This is striking, as one might expect "data control" to have some relationship to privacy attitudes and these variables therefore to move together or affect each other. Evidently though, this is not the case. Moreover, while the swings of *PrivacyConcerns* suggest that how privacy is understood – at least with respect to IMPULSE adoption – has a strong country-specific dimension, this is not the case for the control variables. Finally, several other factors are also important for respondents' adoption decisions, in particular perceptions of usability and their personal openness and interest in new technology.

Table 1. Results of the Regression Analysis

	Dependent variable: *Self-reported likelihood of adopting IMPULSE*			
	Model 1	Model 2	Model 3	Model 4
Age	0.006*	0.008**	0.009***	0.009***
	(0.003)	(0.003)	(0.003)	(0.003)
Gender_Male	-0.072	-0.095	-0.078	-0.078
	(0.086)	(0.084)	(0.084)	(0.084)
Edu_HighSchool	-0.401**	-0.353*	-0.358*	-0.357*
	(0.193)	(0.193)	(0.196)	(0.196)
Edu_University	-0.231	-0.193	-0.187	-0.186
	(0.160)	(0.161)	(0.163)	(0.162)
Income_Q2	0.391*	0.255	0.281	0.281
	(0.228)	(0.224)	(0.228)	(0.227)
Income_Q3	0.070	-0.049	-0.074	-0.074
	(0.207)	(0.207)	(0.209)	(0.209)
Income_Q4	0.079	-0.083	-0.092	-0.093

	(0.188)	(0.189)	(0.192)	(0.191)
Income_Q5	0.228	0.088	0.080	0.080
	(0.171)	(0.172)	(0.175)	(0.174)
Ethnic_Minority	-0.137	-0.158	-0.082	-0.082
	(0.236)	(0.236)	(0.247)	(0.246)
Ethnicity_Refuse	-0.616**	-0.502**	-0.486**	-0.486**
	(0.239)	(0.235)	(0.236)	(0.235)
TechOpennness	0.217***	0.190***	0.188***	0.188***
	(0.044)	(0.044)	(0.045)	(0.045)
PrivacyConcern	-0.032	-0.118***	0.244	0.245
	(0.041)	(0.043)	(0.229)	(0.228)
Usability	0.335***	0.310***	0.298***	0.298***
	(0.027)	(0.028)	(0.028)	(0.028)
ControlDescriptor	0.388***	0.362***	0.374***	
	(0.134)	(0.133)	(0.135)	
DecisionDescriptor	0.346***	0.351***	0.348***	
	(0.132)	(0.130)	(0.130)	
ControlPerception				0.361***
				(0.072)
Country_Denmark		-0.990***	0.865	0.870
		(0.242)	(1.121)	(1.119)
Country_Finland		-0.684***	1.847	1.849
		(0.256)	(1.253)	(1.252)
Country_France		-0.780***	1.428	1.423
		(0.286)	(1.503)	(1.501)
Country_Germany		-0.843***	0.928	0.929
		(0.206)	(1.105)	(1.104)
Country_Iceland		-0.865***	0.809	0.812
		(0.235)	(1.159)	(1.157)
Country_Italy		-0.538**	1.433	1.437
		(0.214)	(1.168)	(1.167)
Country_Spain		-0.325	0.859	0.865
		(0.201)	(1.120)	(1.118)
Denmark_PrivacyCon			-0.431*	-0.432*
			(0.256)	(0.256)
Finland_PrivacyCon			-0.614**	-0.615**
			(0.295)	(0.295)
France_PrivacyCon			-0.501	-0.498
			(0.344)	(0.343)
Germany_PrivacyCon			-0.397	-0.398
			(0.244)	(0.244)
Iceland_PrivacyCon			-0.366	-0.366

			(0.259)	(0.258)
Italy_PrivacyCon			-0.445*	-0.446*
			(0.259)	(0.258)
Spain_PrivacyCon			-0.237	-0.239
			(0.244)	(0.244)
Constant	1.884***	2.956***	1.298	1.294
	(0.338)	(0.410)	(1.100)	(1.099)
Observations	635	635	635	635
R^2	0.312	0.353	0.361	0.361
Adjusted R^2	0.295	0.329	0.330	0.331
Residual Std. Error	1.034 (df = 619)	1.009 (df = 612)	1.008 (df = 605)	1.007 (df = 606)
F Statistic	18.688*** (df = 15; 619)	15.153*** (df = 22; 612)	11.772*** (df = 29; 605)	12.212*** (df = 28; 606)

Note. *p<0.1; **p<0.05; ***p<0.01; standard errors in parentheses.

Interim Conclusion: Findings related to Research Question 2

With regard to RQ 2 – in as far as users believe that SSI gives them "control" over their data, how important is this for driving adoption? – we can thus conclude that such a perception may well have a significant positive impact on adoption. While this is highly plausible, given extant survey evidence that users highly value control over their data (PWC 2021, Spiekermann and Korunovska 2017), the regression results must be interpreted cautiously. At the point in the survey where respondents were asked about adopting IMPULSE, the issue of data control had not yet been raised. Thus it remains unclear whether these respondents really had already formed an idea about IMPULSE giving them control over their data, or whether this notion only came to them in the subsequent items, when it was explicitly raised (which would suggest that the "data control"-variables in the regression are picking up some other underlying factor).

CONCLUDING DISCUSSION

Conclusions and Implications

This paper concludes: Firstly, the claim that SSI systems provide users with "control" over their data and/or identity, and does so via its technology and architecture, is incorrect. On the contrary, SSI by itself not only provides users little more control than established identity technologies do, it is even liable to render them more vulnerable to excessive demands for data; i.e. leave them less in control. If Wallet Histories and ZKPs, which are optional and in the case of ZKPs, technologically immature features, do get built into SSI systems, this *could* mildly improve users' data privacy and control over their data. However, Wallet Histories and ZKPs depend on a conducive legal-institutional framework (e.g. the GDPR) to have this effect. By contrast, without an appropriate legal framework, SSI is liable to turn into a disclosure machine for user data.

Secondly, when presented with the workings and data flows of an SSI system, most users do not seem to conclude that it provides them with a particular degree of "control" over their data. A minority of users however does seem to come to this belief. It remains unclear who these users are or why exactly they reach this interpretation. Indeed, many users seem to struggle to form and apply a clear and coherent idea of what "having control over their data" would mean – unsurprisingly so, given that this is a rather abstract concept that requires a good understanding of digital technologies and ecosystems. However, this means that users may also be quite suggestible in this regard, not least as people seem to find the idea of having "control" over their data appealing.

Consistent with this is the third finding, namely that perceptions that an SSI system gives users' "control" over their data, are significantly positively correlated with the decision to adopt the system.

These findings have several implications. Firstly, marketing campaigns pushing the message that SSI gives users "control" may well boost adoption, at least in the short-term. Given that this claim is objectively incorrect, it is however to be feared that a backlash may follow, too. This would be obviously detrimental to SSI, but also to trust in society in general: users and citizens may well prove less forgiving – and less forgetful – of a broken promise to give them "control" over something as personal and sensitive as their data, than they perhaps are of an overhyped tech gadget or golf club.

These points do not imply a rejection of the identity solutions being developed under the SSI label. On the contrary, the VCs, DIDs and digital wallets offer real benefits for users and service providers. However, the benefits lie in their greater usability, reduced friction and costs and greater data security compared to existing solutions and customary processes. A second implication is thus that SSI developers should focus their development and promotional efforts on these advantages, and avoid the unconvincing and misleading rhetoric about giving users "control". Usability has regularly proven tremendously important for driving adoption (and our own regression results consistently find that usability is significantly predictive of a positive adoption decision), suggesting that this is promising strategy. Thirdly, this may imply the need for a new term for this class of identity solutions, since they hardly make the user "self-sovereign" in any meaningful sense. Fortunately, a good term for them already exists: user-centric identity solutions.

A final and broader implication of this research is the critical importance of locating the design and the analysis of technical systems (whether SSI systems or some other system) within the specific legal-institutional environment that they are to be used in. Depending on the legal-institutional context, the same system may produce quite different effects. Technology design and analysis that ignores these realities is liable to generate unintended and unrecognised consequences, not all of which may be desirable. Conversely, design and analysis that is sensitive to the diverging and idiosyncratic effects different legal-institutional contexts can have on technology use, and the design requirements this implies, can create genuinely beneficial technological solutions.

Limitations and Future Research

This study has limitations. Most importantly, the survey population is not representative, but disproportionately well-educated, well-off and white. However, it is not clear what effect this is likely to have had on the questions of interest here. Well-educated respondents may be harder to deceive than less well-educated ones, implying that a more representative survey might have found higher numbers agreeing that the IMPULSE system gave them "control". However, even well-educated respondents might often lack the specialised knowledge about digital technologies and ecosystems required to accurately assess this question, which would moderate the effect of our respondents being better educated. It is notable that on a number of measures, the attitudes and behaviours related to digital identity systems revealed by our survey population, was similar to the attitudes and behaviour of the general population, as found in several representative surveys.[35] This strengthens our confidence in our specific results. In any case, the larger implications of our argument – that the claim that SSI gives users "control" is untrue, and that marketing SSI on the basis of this claim highly inadvisable – remain unaffected by this possible bias.

A further limitation is that with regard to the "gives me control over my data"/"I get to decide who gets my data"-descriptors, our survey instrument could not distinguish between those respondents who did *not* tick these because they consciously disagreed with these statements, and those who did not tick them because they were unsure or confused. Length constraints on the survey instrument prevented more detailed questions on this point. However, as the key question of interest was what share of respondents consciously *agreed* with these statements, this limitation seems less critical, if still unfortunate. Further research could address this issue by disambiguating and also adding more breadth to this question area. For instance, a number of reflective items, forming latent constructs, could better grasp the nuances underlying agreement or disagreement.

Finally, as already noted, the issue of "data control" was only raised after respondents had been asked whether they would adopt IMPULSE. While it is intuitively plausible that the belief that the system gives one "control" should increase adoption likelihood, it is possible that the significantly positive relationship between ticking the "control"/"decision"-descriptors and the adopting IMPULSE does *not* in fact reflect respondents – at the time of being asked about adoption – having already formed an idea that IMPULSE gives them control and *therefore* wanting to adopt it, but rather some underlying factor. A more systematic test of this relationship would therefore be desirable, for instance by splitting a population sample in two and giving them different information about the system (e.g. one that brands the system as "giving control" and one that skips the topic). However, given the appeal that "data control" has to users, it is likely that such tests would find substantively the same relationship.

More broadly, this paper points to the value of future research that would investigate in more detail how ordinary users understand and make sense of terms like "control", "data sovereignty" or also "data protection" and "privacy friendly" and other data-governance terms. While not the main focus of this research, our paper provides evidence that users may often struggle to form a clear – let alone a coherent – understanding of what these terms mean. How ordinary users understand these terms may well also diverge – perhaps markedly – from how they are used in the specialist discourses of law, policy, technology and

academia, where they were originally coined. This would be quite problematic. These and related terms are the key concepts in which data governance is discussed in the specialist legal, policy and technology communities. Rapid digitisation of (almost) all areas of life means that data governance is increasingly relevant to people's everyday lives. But if the terms that data governance is discussed in – and with which products are advertised to users – are unintelligible or mean quite different (and maybe idiosyncratic) things to lay users than to the specialists, the stage is set for serious miscommunication. Understanding better how ordinary users in fact make sense of these terms is the first step to resolve and avoid such confusion.

ENDNOTES

1. Calculated by summing the total funding for projects contained in the https://cordis.europa.eu/ data base that referred to "self-sovereign identity" in their project description or referenced the term in their key words. No effort was made to disentangle how much of this funding went to SSI development in a narrow sense, and how much to (broadly) related ancillary activities. Accordingly, the headline number should be treated as indicative only.
2. For example, in Germany the Economics Ministry funding program "Schaufenster Sichere Digitale Identitäten" has reportedly provided some €45 million to four projects (Heeger 2020), at least two of which describe their objective as developing SSI solutions (the projects SDIKA [https://www.sdika.de/] and ID-Union [https://idunion.org/]).
3. RQ 1 focuses only on whether users believe SSI would put them "in control over their data", not whether they believe it would give them "control over their identity." The reason for this is twofold. Firstly, as we will see shortly, in many – but not all – regards, to have "control over one's data" and to have "control over one's identity" are identical statements, and the SSI discourse tends to treat them as synonymous. Secondly, while the notion of "having control over one's identity" can be understood in a way that is *not* synonymous with having control over one's data, to construe "having control over one's identity" in this other way turns it into an (even more) complex and abstract notion than "having control over one's data" is, that would be difficult to implement in a quantitative survey.
4. We are grateful to Henk Marsman for alerting us to this thesis. (Private communication from Henk Marsman, 12 February 2024.)
5. We are grateful to Henk Marsman for alerting us to the epicenter.works submission. (Private communication from Henk Marsman, 14 January 2024.)
6. GRADIANT was coordinator of the EU Horizon 2020 IMPULSE project, which developed a prototype SSI solution and studied its impact in the context of public services. The authors were too members of IMPULSE project, and this study was funded as part of the IMPULSE project (see acknowledgements).
7. This asymmetry derives from the sheer complexity of modern data processing and data value chains. Combined with most people's limited attention for what is, *prima facie*, an excruciatingly boring topic, this makes it difficult for even the best intentioned data processor to communicate to their users what is really going on. Of course, many data processors are not well-intentioned, and exploit the possibilities offered by impenetrable legalese and/or manipulative technology design (e.g. "dark patterns").
8. Digital identity systems generally also include some security features, like passwords, PINs or public/private keys.
9. For example, Allen (2016), in what is a foundational document of the SSI movement, speaks about placing identity "back under [the users'] control". Users should be "the rulers of their own identity"

and “the ultimate authority on their identity. They should always be able to refer to it, update it, even hide it.” In the same vein, Sedlmeir et al. (2021) describe a digital identity as “something that a subject has”. Similar language can be found in Dunphy und Petitcolas 2018, Lim 2020, Liu et al. 2020, Bazharnova et al. 2019, Richter and Anke 2021 and Kubach et al. 2020 and references quoted therein.

10. See again Sedlmeir et al. (2021): “A digital identity consists of attributes that can be revoked, deleted, transferred, or exchanged”
11. Understanding the main value of identity to lie in the status/entitlements it confers also has implications for how to think about the plight of undocumented migrants (a use case for SSI frequently referenced in the literature): arguably, their problem is not so much a lack of identity documents, as the unwillingness of states to issue them with new and valuable legal-political status and rights. (Something the states could of course do at any time, if they were willing.)
12. This paragraph is based on Strüker et al. (2021), Sedlmeir et al. (2021), Lim (2020), Kubach et al. (2020)
13. Amazon, like many other internet service providers, may also be able to monitor users and other visitors to the Amazon website through other technologies, like browser cookies, irrespective of whether the visitor has an Amazon account or is logged in.
14. This paragraph is based on Strüker et al. (2021), Lim (2020), Kubach et al. (2020.)
15. Again it is worth remembering that both Google and Facebook, the two most widely used SSO systems, have many further ways of tracking users’ behaviour across the internet, irrespective of whether they use their Gmail or Facebook log-ins to access other services (Christl and Spiekermann 2016).
16. We are indebted to Xavier Martinez and Jaime Loureiro from GRADIANT for talking the time explain SSI architectures, their building blocks, and data flows within them, to us in detail. All remaining errors, needless to say, are our own, as well as the larger argument about SSI, and should not be construed as representing the views of GRADIANT.
17. For a detailed technical discussion of VCs see the W3C draft standard (W3C 2024).
18. For a detailed technical discussion of DIDs see the W3C standard (W3C 2022).
19. Typical transactions could be, for example, presenting one’s state identity card (or information derived from it) in VC form to a bank to prove one’s identity in order to open an account or for a financial transaction, presenting certificates (e.g. one’s child’s birth certificate) to state agencies to access social services, or one’s educational credentials to a prospective employer
20. The (German language) data protection notice on the Amazon.de site including the additional note on Cookies is 13 pages (5026 words) long, and the general contractual terms and conditions 18 pages (6965 words). The additional note on programmatic advertising could not be opened. (Accessed 19 May 2023)
21. Using SSI would though likely be more user-friendly than the current manual data entry, and could provide Amazon with more trustworthy data about the user, if the VC was based on e.g. her state identity card. Among other things, this could reduce the scope for online fraud.
22. See the extensive discussion of privacy risks with VCs in the W3C draft standard for Verifiable Credentials (W3C 2024).
23. The privacy policy and related documents on cookies and interest-based ads of Abebooks.com, for instance, runs to 4348 words; the privacy policy of Alibaba.com to 5560 words. (Accessed 19 May 2023)
24. A detailed account of how the “Building Blocks” system functions is provided in Wang and De Filippi 2020.
25. For instance, merchants from whom refugees made purchases via the Building Blocks system, as well as the payments processors, could not learn the refugees’ identities or account balances. The

biometric data, identifiers, and underlying identity information were stored separately (Wang and De Filippi 2020).

26. IMPULSE – Identity Management in PubLic SErvices (www.impulse-h2020.eu) was an EU Horizon 2020-funded project (European Commission Grant Agreement 101004459) that ran from 02/2021 to 01/2024 and aimed to develop a smartphone-based SSI-style identity solution, trialling this in six pilots mostly in local public administrations across Europe. The authors, and the Fraunhofer Society, participated as partners in the project, responsible mainly for social-political and economic impact assessments, standardisation and roadmapping. Fraunhofer and the authors have no commercial or financial interest in the IMPULSE solution.
27. The exact formulation of the task was as follows: "For many people, it is very important to have 'control over their data'. Having 'control over your data' has many dimensions. Below is a list of some dimensions. Please choose the three most important in your view."
28. IMPULSE uses the European Blockchain Services Infrastructure (EBSI) blockchain (https://ec.europa.eu/digital-building-blocks/sites/display/EBSI)
29. For a detailed technical description of the IMPULSE system and its building blocks see Deliverables D2.10V2, D5.1, D5.2 and D5.4 of the IMPULSE project (Martínez et al. (2023a), Martínez et al. (2023b), Martínez et al. (2022)). The following description is based on and partly taken from these documents, as well as from extensive discussions with the IMPULSE developers from GRADIANT, who are also the lead authors of these Deliverables.
30. It can be viewed at https://www.youtube.com/@impulse_EU. Online banking was chosen as example because it is increasingly common, so respondents were likely to be familiar with it.
31. The question asked "How concerned are you about your privacy when you access services on the internet?" with responses collected on a Likert Scale from 1 ("Not concerned at all") to 5 ("Very concerned"). We have coded "4" on the Likert scale as "concerned" (Note that in the survey instrument, only "1" and "5" were explicitly described as signifying "not concerned at all" [1] and "very concerned" [5] respectively).
32. It is worth noting that respondents who described themselves as "concerned" (Likert 4) or "very concerned" (Likert 5) about online privacy were slightly *more* likely to describe IMPULSE as privacy friendly than those who gave themselves lower "privacy concern" scores.
33. The average age of the survey population is 43.4 years; that of the respondents who chose the descriptor "gives me control over my data" is 41.5, of the respondents who chose "with IMPULSE, I can decide who gets my data" is 43.9.
34. The survey item asked respondents where they stood with regard to the statement "I enjoy trying out new technologies" (Likert scale 1 ("strongly disagree") to 5 ("strongly agree")).
35. Attitudes to using multiple digital identities, experience with passwords, and use of digital public services by our respondents were notably similar to those found in the Initiative D21 E-Government Monitor, a representative survey conducted annually in Germany, Switzerland and Austria.
36. We interpret this value of the ethnicity variable (refusal to disclose ethnicity) as indicating a particularly intense concern over privacy. Note that unlike *PrivacyConcerns*, the sign and significance of *EthnicityRefuse* remains unaffected by the inclusion of the Country variable. This may be related to the small number of respondents (29 individuals) who refused to give their ethnicity, compared to the much larger number (>440) who reported a hightened level of *PrivacyConcerns*. For full discussion see Martin and Metzger (u.r.).
37. We can interpret this to mean that – other things equal – respondents in Bulgaria (the reference category) are significantly more likely to express intention to adopt the system than respondents elsewhere.

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Appendix

Distribution by country of survey respondents who say that IMPULSE gives them “control over their data” / lets them “decide who gets their data”

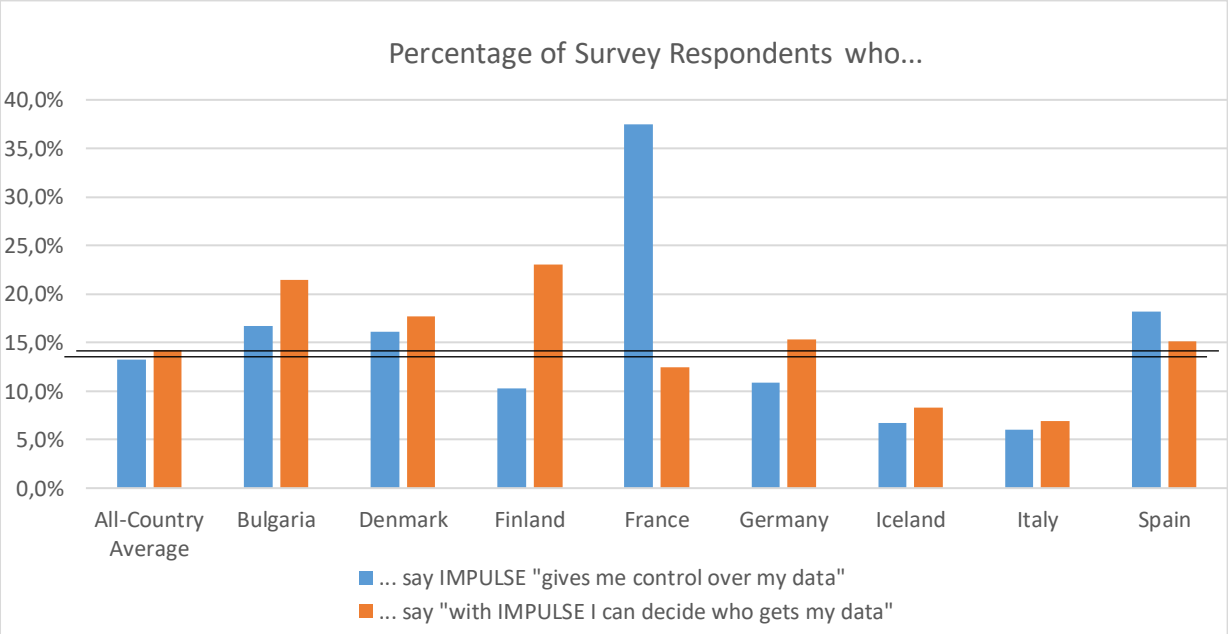

Figure 6. Percentage of survey respondents by country who say that IMPULSE gives them “control over their data” / lets them “decide who gets their data”

Survey Instrument

The text was translated into the languages of the countries surveyed.

Introduction

Thank you for your help!

This survey is conducted by a group of researchers at institutes and universities in Finland, Germany and Austria. Our survey is for a scientific project funded by the European Union. We want to understand what people think about online public services, computers and smartphones, and how they use them. This will help us develop new technology and improve public services online.

By taking the survey, you provide really important input for our research!

The survey is completely anonymous. No information you share can be traced to you, nor can you be traced by any information you provide. You can also withdraw from the survey at any point.

For each completed survey, we will donate 2€ to one of several charities (you can pick!), up to a total of €500 Euros.

Let me thank you again for support

Nicholas Martin, Fraunhofer ISI, Germany

If you have any questions, please feel free to contact me at nicholas.martin@isi.fraunhofer.de

To learn more about our research project, visit https://www.impulse-h2020.eu/

Section 1: Demographics

To understand survey results better, we would first like to collect some background information.

Q1. How old are you?

- Free text box

Q2. What is your gender

- Female
- Male
- Diverse

Q3. What is your highest level of education?

- Completed primary school
- Completed secondary school
- Completed post-secondary school vocational training
- Completed university
- Currently at university
- Currently in post-secondary school vocational training

Q4: What is your annual household income, after tax?
(country-specific quintiles, based on Eurostat data)

- Less than X
- X+1 to XX
- XX+1 to XXX
- XXX+1 to XXXX
- More than XXXX+1
- Prefer not to answer

Q5. What is your citizenship?

- Citizen of [*survey country*]
- Permanent resident of [*survey country*]
- Migrant / non-permanent residency
- Prefer not to answer

Q6. Due to discrimination and for other reasons, minority groups often have distinct views about technology. To help us develop genuinely inclusive technology, we would therefore like to ask you for your ethnicity.

- White
- Minority
- Prefer not to answer

Q7. Do you live in a…

- Rural area or village
- Small or middle-sized town

- Major city [country-specific population number based on size of ~top 5 cities]

Q8. I enjoy trying out new technologies

Strongly Disagree ... Strongly Agree.
1 2 3 4 5

Q9. People have different views on privacy. In general, how concerned are you about your privacy when you access services on the internet?

Very Concerned ... Not Concerned at All
1 2 3 4 5

Section 2: IMPULSE

We are developing a new Log-In system for online services. We would like to get your feedback on it. Please watch the video, which shows the basic elements of our system.

Video here

Qu. 10. Would you use IMPULSE instead of the digital identity (log-in) systems you currently use (like username/password, smartcard, PIN, etc.), if IMPULSE were available?

Certainly not ... Certainly yes
1 2 3 4 5

Qu. 11. *Only for "NOs" (1, 2) at Qu. 9***. Why would you not use IMPULSE instead of the digital identity (log-in) systems you currently use? Tick all that apply**

- I do not want to depend on my Smartphone
- I do not have a Smartphone
- I am worried about what happens if I lose my Smartphone or it is stolen
- I am worried about facial recognition technology
- IMPULSE is too complicated
- I use too few online services to make IMPULSE worthwhile
- I am worried about hackers and identity theft

Qu. 12. For which online services do you think it would be most sensible to use IMPULSE? Please select no more than five

- Online banking
- eHealth (e.g. electronic communication with a doctor to get a prescription instead of going in person)
- Digital vaccination certificate for Covid or other diseases
- Social media
- E-commerce (e.g. Amazon, Airbnb)
- Completing tax returns online
- Registering for social services online
- Email

- Other (free text box)
- None

Qu 13. Please choose all of the following words and phrases that you feel describe IMPULSE.
Convenient ; Easy to use ; Saves time ; Makes signing up for services easier ; Makes logging in easier ; Exciting ; Safe ; privacy-friendly ; interesting ; Unnecessary ; weird ; Complicated ; Creepy ; IMPULSE gives me control over my data ; Dangerous ; Surveillance ; Not useful ; With IMPULSE, I can decide who gets my data ; Other *(free text box)*

Qu 14. Today, many people have multiple digital identities (log-ins), with different usernames/passwords. People have different views and experiences of this. Please tell us which statements you agree with

Strongly Disagree ... Strongly Agree
1 2 3 4 5

- Using multiple digital identities is a hassle, but sensible
- I would prefer to have a single digital ID for all online services and accounts
- I sometimes forget my username/password, or forget which identity to use for a service or account
- I sometimes don't use a service because the sign-up process (when you enter information like your name and address and create a username/password or similar) is too much hassle
- Managing multiple digital identities and ways of identifying myself overtaxes me
- If signing up for services were easier and faster, I would use more services
- If I had only one single, secure digital ID, that I could use for all online services, I would use more services

Qu. 15. With IMPULSE, you create a new digital identity for each online service, and store these identities on your phone, in the IMPULSE App. As we saw in the video, you create these digital identities with photos of your state identity card, but then the photos are deleted. No record of your identity card is kept.

Some European governments have proposed an alternative system: a digital version of your state identity card, that you store on your phone and can use as a single, universal digital identity for all online services – instead of having multiple digital identities like with IMPULSE. Which system would you prefer to use? *Choose One*

- IMPULSE: multiple digital identities stored on your phone but no record of your ID card kept on your phone
- Alternative: digital version of your identity card stored on your phone that serves as a single, universal digital identity

Qu. 16. For many people, it is very important to have "control over their data". Having "control over your data" has many dimensions. Below is a list of some dimensions. *Please choose the three most important in your view.*

- Online service providers have to ask for my consent before collecting or using my data
- Online service providers must provide a short, easy-to-understand privacy policy explaining how they use my data
- Online service providers cannot demand more data from me than necessary to make the service work
- Online service providers cannot refuse me their service unless I allow them to use my data for advertising
- Online service providers cannot use website lay-out and other tricks that manipulate me to give them extra data or data-use permissions
- Online service providers must delete my data if I ask them to

Section 3: Experience with eID and & Digital Experience

Qu 17. Some people are very skilled with computers and smartphones; others are just getting to know them. Please tell us about your skills

Strongly Disagree ... Strongly Agree
1 2 3 4 5

I know how to…

- …use Google or other internet search engines
- …find relevant information on websites of state agencies or the municipal government
- …use email or social media
- …save or store files (documents, music etc.) on my device and retrieve them when I want them
- …use Cloud Applications like Dropbox, iCloud, Google Drive, or SharePoint to store and share documents
- …use online services like online banking, e-government or e-health
- …use Word or Powerpoint or similar applications
- …read a simple computer code and make basic changes to it
- …re-install or update computer programs

Qu. 18. There are many different technologies to give users a digital identity to log in to an online service, computer or smartphone, like username and password, PIN/TAN, Smartcard etc. Please tell us which ones you have used or heard about

	I have used this technology	**I have heard about this technology**	**I have not heared about this technology**
User Name + Password			
SmartCard + PIN-Number			
NemID / MitID *(Denmark only)*			
PIN / TAN			
Fingerprint recognition			
Face recognition			
Voice recognition			
Eye [iris] recognition			
Other [please specify]			

Qu. 19. From the list below, please choose the 3 digital identity (log-in) technologies that you prefer to use for your log-ins. Don't worry if you have not used some of the technologies yet.

- User Name + Password
- SmartCard + PIN-Number
- PIN / TAN
- Fingerprint recognition
- Face recognition
- Voice recognition
- Eye [iris] recognition
- NemID / MitID *(Denmark only)*
- Other [please specify]

Qu. 20. Many online services require you to use a digital identity (log-in), like a username/password, PIN/TAN, Smartcard/PIN or biometric recognition

Please estimate how many *private-sector* online services you regularly use that require a digital identity (log in), like online banking, social media, insurance, Amazon/online shopping, Airbnb, Booking.com, …
Don't worry if you are not 100% sure, just give us your best guess.
Freetext box

Please estimate how many public-sector online services you use that require a digital identity (log in), like completing tax returns online, Covid App, registering a car or your residency, participating on a public discussion forum, registering online for a government service, …
Don't worry if you are not 100% sure, just give us your best guess.
Freetext box

Section 4: Experience with eGovernment

eGovernment means digitising public services, so citizens can do them online: for example complete tax returns, pay municipal bills, register a car or residence, or apply for social benefits.

Q. 21. Have you used eGovernment services (online public services)?

- Yes
- No

Q.22a. *For "Nos"*. Please tell us about why you have not used eGovernment services, and your views about eGovernment in general.

Tick all that apply

- I am not aware of any eGovernment services
- The eGovernment services that exist are not relevant to me
- Going to the public administration in person is faster than using eGoverment
- Doing things in person at the public administration is easier than using eGoverment
- eGovernment feels cold and nonpersonal. I prefer having personal interaction with the civil servants
- I am worried about the security of my data if I use eGovernment
- I would be worried to make a mistake if I use eGovernment
- I would use eGovernment if it was fast, simple and I could be sure my data are safe
- Other Free Textbox

Qu.22b. *Only for "Yes" at Qu.21.* Thinking about your experience with eGovernment, what aspects should be improved the most? Please choose the three most important

- Make signing up for eGovernment (creating a digital identity to use for eGovernment) easier and faster
- Make logging-in to eGovernment services easier and faster
- Make more public services available online
- Make finding information about eGovernment services easier
- Improve the layout of eGovernment websites
- Offer more assistance for using eGovernment (e.g. helplines, chatbots)
- Ensure all eGovernment services can be completed fully online (i.e. no need for any offline steps, like providing physical signatures

End

Many thanks for your time and support!

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BRIDGING THE GAP BETWEEN HUMAN AND TECHNOLOGY: USING EMPATHIC DESIGN STRATEGICALLY TO PROVIDE CITIZEN-FRIENDLY SERVICES

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Abstract: *Finnish cities are undergoing rapid transformations due to technological advancements and shifts in demographic structures. The increasing diversity necessitates a more inclusive approach to digital governance in response to widening societal disparities. This paper proposes a model for developing citizen-friendly services by integrating empathic design with design management, employing benchmarking and systematic literature review methods. Initially, a preliminary benchmarking of five major Finnish cities—Helsinki, Espoo, Turku, Tampere, and Oulu—was conducted to map the prevailing challenges in the strategic application of design principles. A systematic literature review then follows to identify specific challenges in city governance through the lens of design management. Consequently, this study proposes a model that elucidates the connections between the identified challenges and various levels of design management. The proposed model facilitates the strategic decision-making process by incorporating empathic considerations and ensuring the effective allocation of resources to address multiple levels of managerial challenges.*

Keywords: *empathic design, strategic service design, design management, four levels of design management, digital governance.*

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INTRODUCTION

The rapid digitisation, changes in demographic structures, and technological advancements necessitate the evolution of public services to cater to the diverse needs of city stakeholders (Anttiroiko et al., 2014; Madhala et al., 2023). Digitised solutions, being more accessible to a broad array of stakeholders, are increasingly favoured by city administrations as a means to address these challenges (Valkama & Oulasvirta, 2021). However, the relentless pace of technological development complicates the provision of social services (Broekel, 2019), and technology-driven social programmes often fall short of delivering suitable services (Greenhalgh et al., 2018). Moreover, factors such as digital literacy and the availability of compatible devices pose significant barriers to achieving equitable and efficient city governance (Hassankhani et al., 2021; Oliveira et al., 2020). The mere advancement of technology in social services does not ensure its relevance or utility to society (Emslie & Watts, 2017; Greenhalgh et al., 2018). In essence, there is a discernible deficiency in the strategic comprehension of the interplay between human factors and technology within the realm of city governance (Carvalho, 2015; Meijer & Bolívar, 2016; Yigitcanlar et al., 2018).

Service design practices and methods have significantly contributed to city governance over recent decades. For instance, service design has moulded urban spaces and services in the digital age (Loukaitou-Sideris, 2012), established cities' brand identities (Yang & Wang, 2018), seamlessly integrated complex systems (Visnjic et al., 2016), and improved the sustainability and inclusivity of service innovation (Ahern et al., 2014). Furthermore, service design methods play a pivotal role in facilitating strategic organisational transformation within municipalities (Kurtmollaiev et al., 2018) and in fostering user-centred innovation to tackle the multifaceted challenges of urban development (Yu & Sangiorgi, 2018). Since the late 1990s, design researchers have also started to investigate users' emotional responses and highlight the significance of Empathic Design (Mattelmäki et al., 2014). Empathic design not only ignites innovative product ideas (Leonard & Rayport, 1997; Postma et al., 2012) but also encourages engagement with various stakeholders for the development of public services (Lee et al., 2014). In this way, designers' empathy and empathic methodologies advocate for human-oriented service development (Kouprie & Visser, 2009).

However, the application of service design methods in public services, particularly with an empathic approach, is still evolving due to a paucity of practical investigation (Strokosch & Osborne, 2023) and the ever-increasing complexity of stakeholder structures (Wallin & Horelli, 2010). Furthermore, employing conventional empathic service design approaches to empathise with specific stakeholders exposes designers to the risk of neglecting diverse communities and over-empathising with certain groups (Vink & Oertzen, 2018). Therefore, it is imperative to understand the overarching strategies for public service challenges through the lens of design management and empathy. This endeavour is also in alignment with Sustainable Development Goal (SDG) 11 - Sustainable cities and communities - make cities and human settlements inclusive, safe, resilient and sustainable in the sense that design management philosophy and empathic design make cities more inclusive, safe, resilient and sustainable (Biloria, 2021; Mieg, 2012; Sandman et al., 2018; Vogt et al., 2020).

PURPOSE AND SCOPE OF RESEARCH

In addressing the complexities of digital governance, Finland stands as the pre-eminent nation within Europe in terms of the populace's digital proficiency (Thornton, 2022) and ranks eighth globally regarding the capability and preparedness for digital transformation among both private and public entities (Hämäläinen, 2020; IMD, 2023). The foundation of digital competency in Finland is laid by the data-gathering infrastructure established by leading cities, notably Helsinki and Espoo (Ylipulli & Luusua, 2020). Consequently, the robust digital infrastructure in Finland provides researchers with the means to explore current issues at the intersection of humanity and technology. Furthermore, Finnish municipalities are at the forefront of fostering democratic engagement with stakeholders (citizens) in the design of services (Mensonen & Hällström, 2020). Within the public service design framework, participatory platforms are employed to facilitate interaction with citizens (Anttiroiko, 2016), embodying inclusive governance for smart cities (Ylipulli & Luusua, 2020) and endorsing a collaborative approach throughout the service design journey (Jäppinen, 2015). In summary, the service design paradigm and its resultant effects in Finnish cities offer a profound understanding of the strategic application of design principles in engaging with citizens.

Even though the use of technological solutions and integration of design practices have increased nationwide, the share of resources varies widely depending on the city since, for instance, tax income for municipalities is generated per capita or industry. Practices developed to serve design professionals in bigger cities, such as Helsinki and Espoo, typically need to be adapted to work in the context of a smaller city. Quite often, designers working with service delivery and design in smaller municipalities are required to function multi-professionally and act in several roles simultaneously (Palumbo, 2016). In Finland, cities have established flexible design practices that can be scaled to suit city governance depending on its characteristics (Anttiroiko, 2016).

Flexible design implementation is crucial for delivering empathic services to citizens (Schliwa, 2019) and facilitates the identification of the gap between humans and technology in society (Oliveira & Campolargo, 2015; Oliveira et al., 2020). Philosophically, design management is also grounded in understanding emotions and providing user-centred value with empathic considerations (Andresa & Juanitab, 2019; Borja de Mozota, 2003). In this context, the present study investigates the diverse design practices in Finland to unearth human and technological challenges for contemporary city governance.

Defining the Focus

In addition to professional disparities, at least three tiers of management (operational, tactical, and strategic) influence service design processes and vary according to the size of the urban area (Best, 2006). This paper utilises the Four Levels of Design Management: Designence (4LDM), as delineated by de Mozota and Wolff (2019, p.16), to pinpoint the pivotal areas where designers can exert the most significant influence. Borja de Mozota (2006) posits that designers would profit from an understanding of management as a discipline to garner recognition and support from their superiors. The application of design management can transform an urban setting into a more citizen-centric organisation (Hyysalo et al., 2023), augment the city's competitiveness (Meijer & Bolívar, 2016), and thereby facilitate value

creation for organisations (Borja de Mozota, 2006). Design management is quintessential in executing contemporary urban governance to synchronise citizens and technologies (Barns, 2018; Bian & Su, 2022; Mueller et al., 2018). The concept of 4LDM (Mozota & Wolff, 2019, p.16) further echoes design maturity, denoting an organisation's capacity to harness design.

Design maturity pertains to the proficiency of individuals and organisations in employing design philosophy and methodologies (Hambeukers, 2019). Given that design maturity evolves through ladder stages (Dansk Design Center, 2015) akin to 4LDM, the elevated levels in 4LDM signify the sophisticated and matured tasks incumbent upon cities. Design maturity is paramount for empathic design as it facilitates the discernment of authentic needs for human-centred empathic governance (Biloria, 2020; Meijer & Bolívar, 2016; Tanaka et al., 2018). Consequently, this study amalgamates the concept of empathy with design maturity and the four levels of design management to create a systematic literature review.

Here, we investigate the design-related challenges that obstruct or interfere with people from interacting with technology-based services. We propose two main types of challenges that hinder designing novel technology-based services in Finland: 1) human-related challenges and 2) technology-related challenges. In this study, human challenges refer to attitudes, skills and abilities, resources (not enough people, time), and training in service development (Hecklau et al., 2017). Technological challenges address technological limitations, resources (i.e., outdated technology and economy), and data flows in delivering services (Kitchin, 2014).

We recognised these categories in our preliminary study, where we compared the city strategies of five Finnish cities from a design perspective (Hyökki et al., 2023). That study revealed a gap between technology and human users. Here, we state that the gap and the varying resources and sizes between Finnish cities create a need for inclusive and empathic (service) design platforms for public service developers and citizens.

We approach these questions by reflecting on them through two perspectives of design: empathic design and design management. The Empathic design allows practitioners to execute more inclusive and holistic service development by considering citizens' complex situations (Biloria, 2021; Sandman et al., 2018). Additionally, the present study identifies the challenges through the lens of Empathic design. In the Empathic design process, it is important to explore challenges with the question 'What could be?' which is a more open-ended and forward-looking perspective (Biloria, 2021; Sandman et al., 2018). Therefore, the analysis of the literature includes the Empathic design perspective on both the outcomes and processes involved in tackling design challenges. Similarly, design management practices contribute to urban governance by shaping outcomes in accordance with public interests (Carmona, 2016) and enhancing user-oriented technology development (Meijer & Bolívar, 2016). Categorising the hierarchy from a design management perspective can suggest how researchers construct various levels of empathic design activities, which is the main goal of the present research. Thus, the present study explores challenges in city governance with empathic design and design management perspectives.

RESEARCH METHOD

This study consists of two parts: a preliminary benchmarking and a systematic literature review. In order to support our hypothesis of technology-related and human-related challenges,

we conducted a preliminary investigation, or benchmark, of selected city strategies. The goal of this short investigation was to compare the service design practices of particular Finnish cities. This was conducted by analysing websites, blogs, and to understand further the design process, degrees of design contribution, common drivers, and problems, each city's strategy document was also examined.

The preliminary benchmark outcome (title: *Bridging The Gap Between Reality and Utopia: How to provide empathetic services to citizens*) was accepted at the C&T 2023 conference at Lahti, Finland, under the workshop theme, *Designing the City: Challenges and Opportunities in Digital Public Service Design*. It enlightened us with crucial information for our systematic literature review and confirmed that the suggested categories of challenges truly exist. Following the benchmark, researchers conducted the systematic literature review by collecting and screening articles with empathic city governance related keywords from three research databases: Web of Science, ProQuest, and SCOPUS. The process of analysing the data for the systematic literature review consists of three steps: 1) coding of the articles, 2) categorising and tagging the codes (quotes), and 3) recognising the relationships, which meant visual analysis in the Miro board.

Finnish cities are generally considered technologically competent (Ahvenniemi & Huovila, 2021). In this paper, five major cities in Finland were inspected and compared in terms of their service strategies. They varied in design maturity levels and in demographics (e.g. size of the city, population), which was an important selection criterion. These details concerning each city were also taken into account in the comparison process.

Preliminary Study (Benchmark)

Three researchers conducted the benchmark between April and May 2023 and submitted the findings to the C&T 2023 conference in Lahti, Finland. The benchmark results for service design practices and insights are summarised in Table 1.

The rapid comparison between the selected five cities highlights several complicated global problems, or wicked problems, such as climate/sustainability, rapid digitalisation, and equality. Almost every city also mentions Sustainable Development Goals (SDGs) in their strategies. Differences arise when inspecting how cities integrate service design on a strategic level. It seems that Turku, Tampere, and Oulu are recognising the importance of service design. Helsinki and Espoo are already ahead of the other three cities by having clearly integrated service design in the strategy. (City of Helsinki, 2021; City of Espoo, 2021; City of Tampere, 2021; City of Oulu, 2022; City of Turku, 2022).

The benchmarked cities' strategies prioritise the human perspective, seeking to offer easily accessible services and assistance to individuals across all life phases. In many cities, services are perceived mainly as personal experiences (e.g. Tampere and Turku). Every benchmarked city aspires for its services to be user-friendly, interactive and even proactive. Turku and Espoo also consistently use their service data to improve their services. However, the cities seem to function at many levels of management, including operational, tactical, and strategic, depending on their size and structure (Best, 2006; City of Helsinki, 2021; City of Espoo, 2021; City of Tampere, 2021; City of Oulu, 2022; City of Turku, 2022). Helsinki performs the most thorough examination of the influential factors. All cities share many similar drivers: the SDGs, internationality, sustainability, ageing populations, and equal life expectancy. However, the

scale and type of challenges differ. The ageing workforce, for example, has a greater impact on Helsinki than it seems to have in other smaller benchmarked cities. A city's size does matter. The tendency seems to be toward empathy and individual experience, and in practice, cooperation and co-creation seem to be well-accepted approaches to the development of services (Cities of Helsinki, 2021; Espoo, 2021; Tampere, 2021; Oulu, 2022; Turku, 2022).

Table 1. Benchmarking Results for Five Finnish Cities [Source: Bridging The Gap Between Reality and Utopia: How to provide empathetic services to citizens].

City	Service Design in the city strategy	Common Drivers	Human-related Challenges	Technology-related Challenges
Helsinki	yes	SDGs, sustainable urban development, functionality, internationality, equality	Ageing workforce, socioeconomic differences, pandemic recovery	
Espoo	yes	SDGs, digitalisation, internationality, sustainability, fairness	Ageing, population, pandemic recovery	Technological literacy
Turku	Not clear	SDGs, sustainability, internationality, meaningful life, Vision of Competence 2040		
Tampere	Not clear	SDGs, internationality, sustainability, equality		
Oulu	Not clear	Sustainability, internationality, safety, European Capital of Culture 2026		Technological literacy

The missing data in Table 1. suggests that certain challenges were difficult to interpret or not clearly addressed in the strategy materials. From a design perspective, a profound understanding of the issue and identifying the main obstacles is a critical first step, which we continue here in this study. In addition to recognising the gap between technology and its human users, two other findings from the preliminary study can be stated: 1) different Finnish cities have different levels of design maturity when it comes to executing empathic design, and 2) the primary goal of design activities is to provide answers for problems relating to both human and technological obstacles.

Systematic Literature Review

The search for articles analysed in this literature review started by identifying the keywords of a key paper read for our earlier article (Hyysalo et al., 2023). The article included the following keywords: city organisation, public sector, service design, and human-centred design. Based on these keywords, two different kinds of modified combinations of these keywords were tried in the same database. This led to Initial Search A and Initial Search B (see Table 2), from which

Initial Search A led to too few results, and Initial Search B included too many international cases. Based on Initial search B, Refined search B2 was performed. However, more databases were needed. Thus, the search (Refined search B3) was extended to ProQuest and SCOPUS. The results from the databases were combined, and duplicates were removed, resulting in 119 articles which were deemed satisfactory.

Table 2. The Overview of Database Searches for the Literature Review.

Stage	Database	Keywords	Result (articles)	Reason for refining the search
Initial search A	Web of Science	ALL=(Public service design, empathy, experience design, design challenges)	11	Too few results
Initial search B	Web of Science	ALL=(service design, city design, emotional design, design challenges)	94	Too many international cases
Refined search B2	Web of Science	ALL=(service design AND city design AND Finland AND challenges)	99	Another database needed
Refined search B3	Web of Science + ProQuest + SCOPUS	ALL=(service design AND city design AND Finland AND challenges)	119	**Result satisfactory**

After satisfactory search results, two filtering rounds were executed in order to find the most relevant articles for closer analysis and review. First, papers with criteria ”not Finnish perspective” or ”other field of study” were omitted, resulting in 75 articles. The second filtering round focused only on design perspective, the omitting criteria being ”not design perspective”, resulting in 24 highly relevant papers for this study (See Figure 1).

Figure 1. The article selection process.

The analysis of the remaining 24 papers was conducted by coding them thematically in NVivo initially to two main categories: ”technological challenges” OR ”human challenges” by three researchers. Researchers considered the process and outcome of each project by asking questions such as, 'What could be the future of the city with these research outcomes?' and 'What could be the impacts on citizens?' to validate the empathic design practices found in the literature. In addition, everyone was allowed to add new categories according to their consideration if needed. After two discussion sessions with all three researchers, these categories were organised with an affinity diagram in Miro.

Analysis of the Data

Affinity diagramming was utilised to analyse the data. As mentioned, the process of analysing the data progressed in three steps: 1) coding of the articles, 2) categorising and tagging the codes (quotes), and 3) recognising the relationships, which meant visual analysis in the Miro board. In addition to categorising the codes, The Four Levels of Design Management: Designence, defined by de Mozota and Wolff (2019), was applied to tagging individual codes to address the crucial places where designers can make the most significant impact. Tagging challenges with the Four Levels of Design Management also helped researchers recognise relationships between the categories.

As mentioned, after coding, seven themes or categories of challenges were recognised in addition to the main two (human and technology-related): environmental, geographic, sustainability, service-related, resource-related, systemic and management. In order to narrow the scope to fit our research questions better, some categories were combined, and subcategories were created based on careful consideration and discussion with all the researchers. Service and design-related categories were combined under the main category of service-related challenges. There was also a diligent discussion about environmental and sustainability challenges, after which it was decided to distribute clear environmental themes under environmental challenges. Since themes often overlapped with each other, creating artificial borders for categories was challenging, and eventually, some categories became part of multiple main categories. In addition, it was decided that sustainability-related challenges alone are too broad a theme for this study, so it was also distributed into relevant parts between other categories. Geographic challenges and systemic challenges were also challenging categories to integrate.

Table 3. The Analysed Categories.

Main categories	Subcategories
Human-related challenges	population, social structures, professional challenges, sustainability, geographic challenges
Technology-related challenges	data-related challenges, types of technologies, smart technology, a need for innovation
Environmental challenges	sustainability-related challenges
Management-related challenges	roles, resource-related challenges, geographic challenges
Service-related challenges	design-related challenges, service-quality challenges, solutions
Systemic challenges	sustainability-related challenges

Eventually, six main categories were inspected more carefully (see Table 3). Human-related challenges and technology-related challenges remained our main categories, and the focus was primarily on them. Human-related challenges addressed subcategories in themes such as population (mainly growth and structure), social structures (for instance, lifestyle, social inequity and communication), professional challenges, sustainability, and geographic challenges (for example, logistics, transportation in general, locations of facilities).

Technology-related challenges included subcategories of data-related challenges (for instance, disruptions in data flows, multiple incompatible data sources, overall view), types of technologies (multiple different, outdated or too novel) and a need for innovation (both too rapid and too slow). Human-related challenges and technology-related challenges seemed to intertwine with each other.

RESULTS

Researchers utilise main and subcategories to elicit the hierarchy of design management challenges for managing a city. A framework encompassing human, technology, management, service, system and environment challenges is structured by design management hierarchy, 4LDM. In addition, a model of city governance for design challenges is derived from the framework and the thorough review of the selected literature.

A Framework of Design Management Challenges for City Governance

As described in Figure 2, the human challenges at the strategic level are related to Inequality, Power structures, Social impact and a deeper understanding of natural systems. For example, the City of Turku in Hodson et al. (2023) tackles the balance of natural resource challenges from the strategic approach and envisions the future technology development plan by thoroughly comprehending the city's resources. Technological challenges on the same level are also about power structures but more about data and privacy on a larger scale. The cultural level of human challenges contains cultural differences, expectations, attitudes, beliefs, and, from a professional perspective, difficulties in interdisciplinary work. Technological challenges at this level include existential change (embodied vs. virtual) and socio-digital solutions. On a functional level, human challenges touch on difficulties in communication, a large number of stakeholders, and a need for a better understanding of social processes. On the other hand, technological challenges on this level point out user autonomy issues and the need for understanding technology. On an operational level, human challenges are related to logistics, population growth, power distribution and interdisciplinary cooperation. Technological challenges also include logistics, material management, and data.

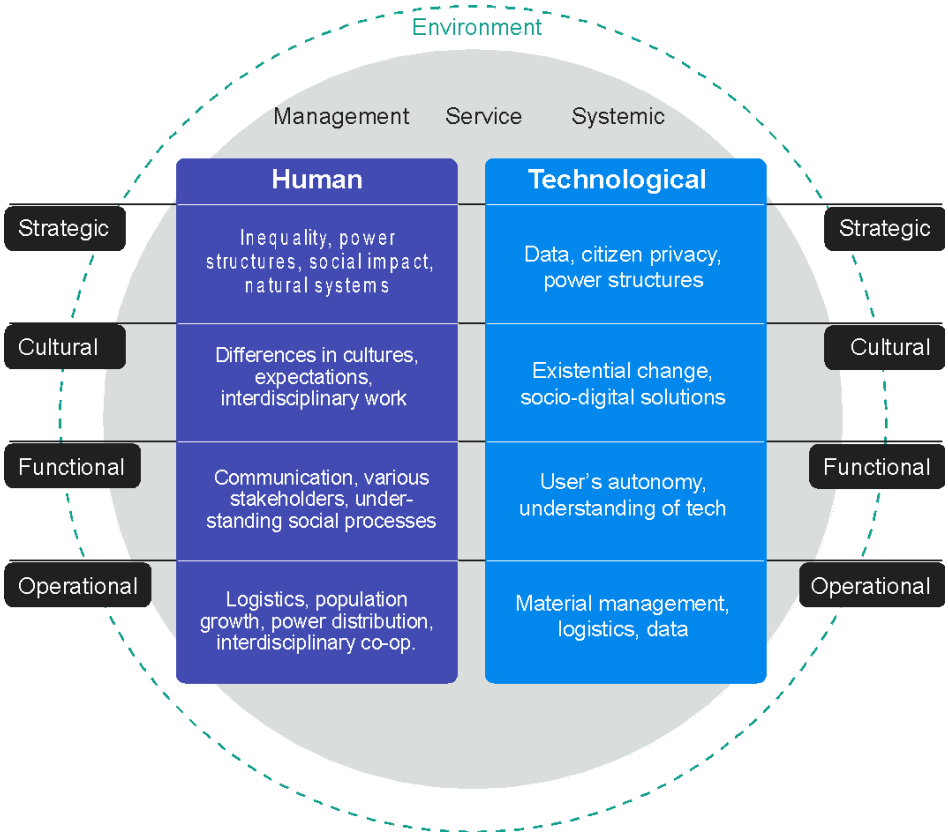

Figure 2. The framework of city governance challenges in 4LDM.

Other categories that have an impact on human and technology challenges were also recognised: management-, service-, and systemic-related challenges. In addition, environmental challenges, including sustainability, need to be taken into account in every step. The main themes of challenges in human and technology categories are arranged according to the four levels of design management. Other categories (management, service, systemic and environment) also have their impact placed on the outer rim.

The Categories of the City Governance Challenges

The results of the systematic literature review were not only categorised but also arranged according to the four levels of design management, as summarised in Table 4. It was possible to point out the design process's challenges directly.

Table 4. The Categorised Human and Technological Challenges by 4LDM.

4LDM	Human challenges	Technological challenges
Strategic	**Inequality** (Hodson et al., 2023), **Power structure** (Pirinen et al., 2022; Rönkkö & Herneoja, 2021; Suomalainen et al., 2022), **Social Impact** (Hodson et al., 2023), **Natural systems** (Alam & Porras, 2018; Chaowen & Fricker, 2021); Jakstis et al., 2023; Luusua et al., 2017; Mesimäki et al., 2019; Ojala et al., 2015)	**Strategic data management** (Laihonen & Mäntylä, 2018), **Citizen privacy** (Ehrenberg & Keinonen, 2021), **Power structure** (Pirinen et al., 2022; Rönkkö & Herneoja, 2021; Suomalainen et al., 2022)
Cultural	**Cultural diversity** (Di Marino & Lapintie, 2015; Di Marino & Lapintie, 2020; Hyysalo et al., 2023; Laihonen & Mäntylä, 2018), **Cultural demands** (Vladykina et al., 2019), **Interdisciplinary work** (Rönkkö & Herneoja, 2021)	**Existential change** (Vladykina et al., 2019), **Socio-digital solutions** (Di Marino & Lapintie, 2020; Pirinen & Tervo, 2020)
Functional	**Communication** (Di Marino & Lapintie, 2020; Hyysalo et al., 2023; Laihonen & Mäntylä, 2018), **Diverse stakeholders** (Pirinen et al., 2022; Suomalainen et al., 2022), **Understanding social processes** (Di Marino & Lapintie, 2020; Pirinen & Tervo, 2020)	**User autonomy** (Ehrenberg & Keinonen, 2021), **Understanding of Technology** (Hodson et al., 2023; Pirinen & Tervo, 2020)
Operational	**Logistics** (Ojala et al., 2015), **Population growth** (Ehrenberg & Keinonen, 2021; Parantainen & Meriläinen, 2003), **Power distribution** (Pirinen et al., 2022; Rönkkö & Herneoja, 2021; Suomalainen et al., 2022), **Interdisciplinary cooperation** (Hyysalo et al., 2023; Pirinen et al., 2022; Rönkkö et al., 2018)	**Material management** (Ehrenberg & Keinonen, 2021; Rönkkö & Herneoja, 2021), **Logistics** (Ojala et al., 2015; Parantainen & Meriläinen, 2003), **Operational data management** (Jääskeläinen & Lönnqvist, 2009; Laihonen & Mäntylä, 2018; Rönkkö et al., 2018)

Another result of this study was also the phenomenon of how the challenges of human and technology categories are distributed on four levels of design management. Challenges in the human category are focused on the strategic level, and challenges in the technology category can mostly be placed on the operational level (See Figure 2). The rigorous activities at the specific design management level imply the practitioners' focus on design management and empathic design. In contrast, the less rigorous levels can be interpreted as the finalising level. For example, management activities of societal value begin at the strategic level and are finalised when operational activities are determined (Steyn & Niemann, 2014). Although city governance is not linear, this observation indicates the crucial starting point for managing empathic design activities.

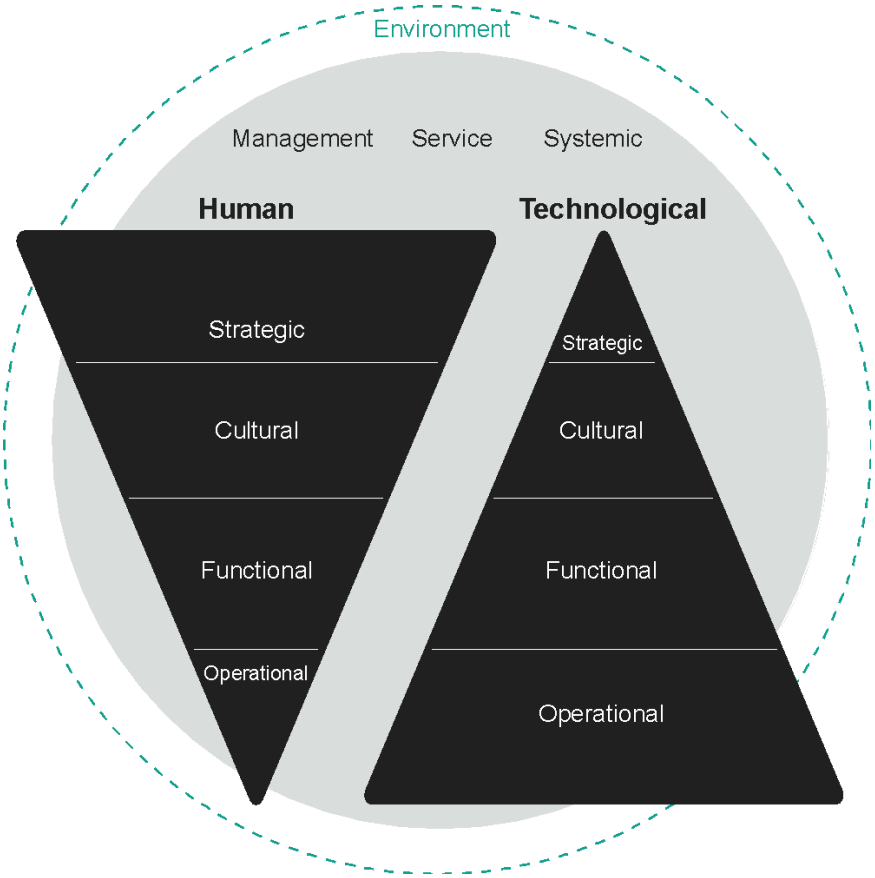

Figure 3. The model of city governance for design challenges.

The challenges of human and technology categories are emphasised differently on the four design management levels. The area of each level represents the relative focus on the challenges. For example, the human challenges in city management are mostly dealt with by strategic vision and planning, while operational activities are dominant for technological challenges. However, fewer activities at a level do not mean a less critical level. Ojala et al. (2015) describe logistics management as being executed in simple and limited activities. However, it needs to be planned with a comprehensive understanding of natural resources, social impact and equality among cities. Instead, Figure 3 can be interpreted as the general tendency of the current city governing process.

FINDINGS AND DISCUSSION

The analysis in our study only scratches the surface. There is a potential to gain a deeper understanding of design challenges on different design management levels if the categories suggested here are studied further. More profound and overall understanding is needed from various perspectives, and interdisciplinary cooperation needs to be valued. However, paying attention to the levels of design management from an empathy perspective provides a valuable tool for designers to approach challenges in modern society. As we live in times when it is

crucial to think in a systemic way when facing a myriad of complex challenges, empathetic design applied consciously to specific design levels may help bridge the gap between different groups of people. Tuomala and Baxter (2019) studied how an empathetic approach throughout the design process assists in the context of politics to unite people for decision-making. The empathetic decisions made on a political level related to technologies we use in everyday life have the possibility of supporting people by using services offered via various technologies, such as digital health services or online immigration services (Sustar & Mattelmäki, 2017).

In addition, Tracy and Hutchinson (2019) argue that the empathic understanding of users at the operational level facilitates the relevant design application in service. The designer's empathy also promotes the strategic design of autonomous cars (Pettersson, 2017). Hence, empathy enables designers to tackle complex societal issues and orchestrates the available resources to strengthen the city's ecosystem (Visnjic et al., 2016). In this context, this study's proposed model and categorisation allow practitioners to recognise the current position and prepare related activities.

As researchers consider empathic design practices in city governance, human challenges may appear dominant in the categories outlined in Table 4. However, technological challenges are equally significant for delivering empathic services to citizens by empowering them through personalised solutions (El-Haddadeh et al., 2019; Sepasgozar et al., 2019) and increasing the transparency of the decision-making process (Webster & Leleux, 2018). Furthermore, as shown in Table 4 and Figure 3, contemporary human and technological challenges in city governance are intertwined and have cross-domain impacts (Barns et al., 2017; Jiang, 2021; Mondschein et al., 2021). For example, the power structure of an organisation represents both human and technological challenges (Pirinen et al., 2022; Rönkkö & Herneoja, 2021; Suomalainen et al., 2022), yet it empowers subsidiaries at the operational level (Pirinen et al., 2022) and facilitates smooth communication at the functional level (Di Marino & Lapintie, 2020). Therefore, the findings underscore the need for a balanced investigation of human and technological challenges in city governance.

Additionally, empathic design has been embedded in managerial activities such as Human-centred design (Hess & Fila, 2016; Lee, 2014; Thomas & McDonagh, 2013) and Experience design (Andresa & Juanitab, 2019). However, emotions and empathy in design practices still need rigorous investigation in complex managerial circumstances (Balaam et al., 2019; Guo et al., 2021). Since a city is a socioeconomic network of people (Alexander, 2019), we need more systemic information on resources, differences, challenges and possibilities related to service design in the public sector. Furthermore, service design methods provide inexpensive ways to develop services with various stakeholders (Stickdorn et al., 2018). As we identified in Table 1, all benchmarked cities implement co-design or participatory design methods for creating services. In this context, the other key contribution of this study is to ascertain the empathic design activities throughout the city's governance in four discrete management levels.

CONCLUSIONS AND FUTURE STUDIES

The empathic design of a city enriches citizens' everyday experiences (McDonagh et al., 2003). Developing a service culture and preparing for the future requires customer understanding and empathy from municipal organisations. Korpikoski describes how organisations can develop

empathy and the importance of empathy in organisations or communities (Korpikoski, 2022). For example, the technological literacy challenge in Table 1 alerts us not to assume citizens' technological literacy. There might be more co-design participants who need technical support. For these changes to occur, a more comprehensive understanding of design management and learning a new way to co-develop with customers/citizens are required. We should create a vision of utilising these resources further in terms of service design management and empathy.

Firstly, continuous efforts to investigate sub-category items at each 4LDM level are necessary. As described in Table 4, some challenges, such as the Understanding of Technology (digital literacy), only existed in the fourth Industrial Revolution. As society becomes dynamic and changes, there will be more complex and new managerial challenges for city governance (McPhearson et al., 2016; Visnjic et al., 2016). The framework (Figure 2) and model (Figure 3) aim to propose a platform that facilitates the categorisation of challenges for determining macro-level activities but not the definite items for each management level. It is also essential to clarify whether service design tools and methods are executed to reflect the practical needs of citizens. For example, Jyrämä and Mattelmäki (2015) argue that the possibility of individual designers influencing public sector operations is still limited.

Even though an understanding of design management combined with an empathic design approach seems to aid in bridging the gap between human and technological challenges, some crucial aspects still need to be considered. In other words, design tools and methods must be more inclusive and relevant to the city's strategic focus (Bianchini & Parkinson, 1993; Stevens & Franck, 2015). To get to the strategic level with design tools, researchers should strengthen their understanding of (service) design management and the importance of empathy. Lastly, but most importantly, it is necessary to develop an instrument which prevents over-empathising a particular group. Balanced empathy among communities and organisations reduces biased views within society (Stephan & Finlay, 1999). From the designer's perspective, too much empathy for a single audience diminishes the service quality (Bove, 2019). Therefore, the systemic instrument must be placed to manage the empathic design activities.

IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

The proposed model in Figure 2 demonstrates the sub-themes of governing challenges. The illustration in Figure 3 summarises the strategic focus on each design management level. Practitioners can determine the strategic focus of tackling social issues by cross-referencing these diagrams. For example, suppose a city wants to solve issues related to Inequality. In that case, the city officers should start questioning related to the Strategic level of design management, such as, "Why is there inequality in our city?" and "Why does it matter to all citizens?". Then, the officers must narrow the scope to the Operational level. On the other hand, if citizens' understanding of technology (technical literacy) matters to a newly developed digital solution, officers need to ask Functional level questions, such as "How does the solution approach citizens?" and "How can it be simpler and easier?". These self-questions can be further developed into strategic-level decisions, such as aligning the vision of new technology development with the city's brand identity. In short, researchers and practitioners can easily determine the key activities by continuously investigating the challenges shown in Table 4.

ENDNOTES

1. **4LDM:Designence**. 4LDM stands for the Four levels of Design Management proposed by Borja de Mozota (2006). The four levels of design management are proposed in Borja de Mozota's initial article (2006) and further developed in Borja de Mozota and Wolff (2019). Designence is the name of a company that develops the value-measuring model at four levels. 4LDM in this research represents the Four levels of Design management proposed by Borja de Mozota (2006) and Borja de Mozota and Wolff (2019).

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THE ROLE OF DIGITAL TECHNOLOGIES IN URBAN CO-CREATION PRACTICES

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Abstract: *Citizen engagement in urban planning is essential to designing urban spaces that are just and responsive to societal challenges. Consequently, local stakeholders are invited into urban co-creation processes. Digital tools are often used in this process to shape urban futures together. This paper explores what role digital technologies play in urban co-creation through five case studies from European cities that were presented at a workshop during the 11th Communities and Technologies conference. The Co-Design Framework is used to analyse the cases and understand how digital tools support collaboration on different levels throughout the design cycle. The findings help to design more effective digital tools for urban co-creation and provide an analysis methodology to compare and contrast urban co-creation practices across cases varying in scale, time, and utilised tools.*

Keywords: *urban co-creation, digital technology, participatory planning, co-design framework, tactical urbanism, placemaking*

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INTRODUCTION

Citizen engagement in urban planning is essential for cities to design public spaces that are adequate, just, liveable, and responsive to societal challenges such as increasing population, economic challenges or climate change. Urban planning innovations are most successful when they result from a collaboration between governmental officials, citizens, and local entrepreneurs (Custers et al., 2020; Mulder, 2012). Consequently, residents and other local stakeholders are invited into urban co-creation processes, to identify challenges and co-create solutions by working with the city. Following various approaches, such as urban living labs (Mäntysalo, 2016), tactical urbanism (Lydon et al., 2015), and bottom-up innovation (Niederer & Priester, 2016), urban stakeholders collaborate on finding solutions to societal and urban planning challenges.

Previous work studied how such urban co-creation processes lead to changing roles and responsibilities of the involved actors and in what way such initiatives can be best facilitated (Leminen et al., 2012; Puerari et al., 2018; Slingerland et al., 2019). These collaborations require an innovative way of working and the creative competencies of the involved actors. Examples of such competencies are active listening, empathy, observation skills and perceptiveness, (self-)reflection, ideation, and imagining and prototyping of solutions. The facilitation of such creative collaborations requires preparation, careful facilitation, and the introduction of the right tools.

Co-creation starts with understanding the needs of the different stakeholders and reaching a shared problem definition and solution space (Sanders & Stappers, 2008; Steen, 2013). This is facilitated by various tools and methods, often based on social science research and design practice, that have extensively been studied in the fields of human-computer interaction (HCI), participatory design (PD), and interaction design. However, challenges and barriers related to inclusion, reaching consensus, and showcasing long-term impact remain to involve urban stakeholders in co-creation (van de Wetering & Groenleer, 2023; Visser et al., 2023).

Strongly driven by the COVID-19 pandemic, researchers and practitioners recently sought to address these issues by introducing digital technologies in urban co-creation (Cortés-Cediel et al., 2021). Digital technologies, in combination with analogue tools, may help to democratise urban co-creation: many residents nowadays use digital technologies, e.g. to navigate the city (Google Maps), to chat with friends (WhatsApp), and to build a (virtual) network on social media platforms. At the same time, governmental services, for example renewing an identity document, are increasingly being moved to the digital space. The number of digital services, functionalities and capabilities is growing fast and addresses all areas of life, potentially reshaping existing governing mechanisms.

Although more use of digital technologies is seen in urban planning and city services, co-creation processes and participation of citizens in development processes are still often supported through mainly analogue tools and paper-pencil techniques. This raises questions and opens up issues in digitalising such processes by harnessing the existing digital knowledge of citizens for participation and co-creation processes in urban planning and further fields of application.

This paper explores what role digital technologies play in urban co-creation through five case studies from Europe (Brussels, Munich, Rotterdam/The Hague, Vienna), Rotterdam

(Netherlands), Salzburg (Austria), The Hague (Netherlands), and Vienna (Austria). It illuminates at which stages of the design cycle digitalisation adds value to urban co-creation, and at which stages it is not supporting the process. The aim of this exploration is to untangle digitalisation in urban co-creation and to formulate propositions on when and how to apply digital technologies in urban co-creation practices.

After discussing the existing discourse on urban planning, co-creation, and digitalisation in the next section, the methods outline the five selected case studies, presented during a workshop at the 11th Communities and Technologies Conference in 2023, and how these are analysed using the Co-Design Landscape framework (Gaete Cruz et al., 2023). The five case studies are then subsequently described in the results. The discussion reflects on both how the framework helped to contrast and compare the case studies as well as when and how digitalisation supports urban co-creation and at which stage of the design cycle.

BACKGROUND

The next section reviews seminal work on collaborative processes and co-creation in urban planning and considers how digitalisation has entered this domain.

Paradigm Shift Towards Collaborative Urban Planning

Citizen participation in urban planning emerged in the 1960s as a critique and reaction to functionalism and comprehensive planning (Allmendinger, 2009), approaching the city as a system controlled from above by expertly prepared, ideal, large-scale master plans that were inflexible in their object orientation. In consequence, academia and professionals increasingly stressed the significance of involving citizens and communities in planning processes. Jane Jacobs and Lewis Mumford particularly emphasised the need for urban planning to embrace the intricate dynamics of city life in its architectural design. Jane Jacobs likened streets to the "lifeblood" of urban communities (Jacobs, 1961), while Kevin Lynch asserted that the physical layout of a place reflects its social fabric (Lynch, 1972). Dolores Hayden advocated for putting "places" at the core of urban landscape history (Hayden, 1988, p. 18). Urban planning shifted towards a more argumentative approach which has led to the gradual replacement of modernist comprehensive planning with incrementalist, participatory, communicative, and embodied methodologies (Healey, 1996).

Today, urban planning is reconceptualised and increasingly organised as a collaborative process. New methods and procedures are expanding or replacing established ones with informal participation methods such as neighbourhood walks, discussion forums, storytelling workshops, and pop-up events in the public space becoming part of the standard repertoire (Harris, 2002); the chronological sequence of planning processes is dissolving; new planning instruments are being introduced; and planning is partially leaving its original institutional framework, the state planning authority (Günther, 2004). Partnerships, networks and negotiations to coordinate the actors involved and their actions have gained relevance in urban planning processes. Healey introduced the concept of "stakeholding" (Healey, 1998, p. 69) as central in collaborative urban planning, recognising the diverse nature of stakes in places and calling "for the complete range of stakeholders to be acknowledged in the

process" (Harris, 2002, p. 35). In collaborative settings, stakeholders come from various sectors (public, non-profit, community, private, academia) and knowledge fields (strategic, transdisciplinary, socio-cultural) (Webb et al., 2018), with different interests, aims, knowledge and skills (Baibarac & Petrescu, 2019). Thus, places "become formed as the product of competing and collaborative groupings in space and may sustain multiple meanings and references contemporaneously" (Harris, 2002, p. 34); constituting participation as a terrain of contestation, where power dynamics continually redefine the scope of engagement (Cornwall, 2008).

The goals of collaborative urban planning are manifold (Pokharel et al., 2022). It can empower citizens (Arnstein, 1969), enable collective social learning processes (Collins & Ison, 2009), build trust (Coleman, 1988), create mutual understandings and resolve conflicts (Susskind & Ozawa, 1984), extend opportunities in public decision-making processes (Günther, 2004), contribute to solving complex issues while improving the outcomes' legitimacy, operability, context-specificity (Baibarac & Petrescu, 2019; Gaete Cruz et al., 2021; Mulder, 2015), the development of inclusive, sustainable and just urban spaces, and ultimately a transformation in urban governance practices (Karacor, 2014).

However, collaborative urban planning and participatory practices are facing manifold challenges. Studies have identified a lack of transparency and accountability (Stokes et al., 2020), a disconnection between governments, planning authorities and communities (Foth, 2017), the exclusion of residents' concerns and needs (Bhardwaj et al., 2021; Innes & Booher, 2004), the dismissal of citizen knowledge by planners (Buil et al., 2016), a lack of inclusiveness, representativeness, and plurality of voices (Kohon, 2018), low accessibility and a lack of interactivity (Du et al., 2020), time-consuming methods and skill requirements (Chess & Purcell, 1999); lack of trust (Bizjak et al., 2017), the challenge of complex decision-making and reaching consensus (Boukhris et al., 2016), a lack of reflection on the complexity of cities as systems (Poplin, 2014), and a persisting dominance of top-down approaches (Bizjak et al., 2017).

Collaborative Planning Meets Digitalisation

The introduction of digital technologies in participatory urban planning enables new ways of communicating, collaborating and harnessing the diverse knowledge and skills of the multiple actors involved in these processes (Giannoumis & Joneja, 2022). It has the potential to facilitate the dialogue between different actors and to empower a "more communicative action-oriented process of planning and city creation" (Houghton et al., 2015). The use of digital interfaces, online platforms, location-based games or immersive environments creates different "engagement channels" (Fredericks et al., 2018) that enhance processes of local networking, exchange, discussion, community learning and action, thereby allowing for a collaborative approach with the potential of democratising urban planning (Hovik & Giannoumis, 2022; Tomitsch, 2016).

Digital technologies, with the purpose of enabling collaborative urban planning, are not developed to replace face-to-face encounters (Zurita et al., 2015) and most studies urge for a combination of analogue and digital methods (Küstermann & Bittner, 2021). As such, they are seen as a means to tackle problems in participatory processes (i.e. lack of representativeness, transparency, and needs-orientation (Chaves et al., 2021) and to

strengthen citizen participation (Buil et al., 2016), to promote public dialogue, to increase accessibility and flexibility (Zurita et al., 2015), to enable community and social network building (Bizjak et al., 2017); to enhance citizens' ability to co-create, collaborate and participate in decision-making (Khan et al., 2017), to enable playful and alternative production and exchange of multi-perspective knowledge (Poplin, 2014), and, ultimately, to improve efficiency of urban management and planning, and to increase legitimacy, acceptance and transparency in decision-making (Mata et al., 2021; Yigitcanlar, 2010). While digital technologies have a high potential to improve collaborative urban planning processes, there are several challenges: some participants may lack access to digital technology, skills, and resources (Fredericks & Foth, 2013), digital tools are often preconfigured and designed to be used in a particular way, and interaction between the participating stakeholders may be limited (Hovik & Giannoumis, 2022). Another challenge is the limited knowledge and state of the art regarding the combination of analogue and digital methods to engage the different stakeholders.

Using Digital Tools in Urban Co-creation

Utilising design methods and practices for co-creation offers a promising avenue to tackle the issues outlined above and to foster collaborative urban planning. Co-creation is an iterative, reflexive, and highly dynamic approach (Itten et al., 2021). It includes “linear co-design processes and consensus building methodologies [...], but goes far beyond them, becoming a complex, articulated and often contradictory process” (Manzini & Rizzo, 2011, p. 200). Co-creation processes require shifting between envisioning and various activities, alternating between levels of specificity and abstraction (Bratteteig & Wagner, 2012).

The literature on digitally enabled co-creation provides some insights that are relevant in the context of co-creation activities with citizens. For example, digital platforms can increase citizens' intentions to take part in co-creation processes, and digital technologies can augment coproduction by enabling structural and cultural factors that act as enablers or barriers to digitally enabled coproduction (Jalonen et al., 2021). Additionally, digital technologies can support the co-creation of public value in coproduction between the government and citizens (Lember et al., 2019).

Untangling Urban Co-creation through the Co-Design Framework

Sanders & Stappers (2008) highlight the transition from user-centred design to co-design, showing how increasingly researchers and designers engage with stakeholders in "the fuzzy front end", the design stage where often it is not clear what the deliverable of the design process might be. Even when prototyping digital tools, often low-fidelity methods such as card games or paper and pencil are used in the early stages of the process (Baibarac & Petrescu, 2019).

The Co-Design Framework (Gaete Cruz et al., 2023) shows how collaboration may occur in different steps of the co-design process. The Framework uses a simplified ladder for the collaboration axis (vertical), drawing from Arnstein's ladder of participation (Arnstein, 1969). Arnstein had proposed a metaphorical ladder, framing citizen participation as a question of power. Each ascending rung represents increasing levels of citizen agency, control, and power. Additionally, Arnstein views participatory power on a continuum that moves from nonparticipation (no power) to degrees of tokenism (counterfeit power) to degrees of citizen participation (actual power).

Gaete Cruz et al. (2023) remove both the bottom and the top extremities of Arnstein's ladder. The authors also signal that they understand collaborative dynamics as "simultaneously bottom-up, top-down and peer-to-peer" (p.269), rather than strictly in a linear manner. On the Y axis, the framework maps out four stages typical in design cycles: research, analysis and synthesis, projection (or ideation), and selection (or decision-making). Thus, different levels of collaboration can be encountered in different stages of design cycles, depending on the aims and other contextual factors. The framework provides a useful way to untangle how and when collaboration may happen in urban planning, with a focus on process, and on the methods used. We, therefore, opted to use the co-design framework to map and analyse the selected case studies, aiming for a deeper understanding of their methodological similarities and the mix of digital and analogue tools.

METHODS

The Co-Design Framework has been selected from the literature as a conceptual lens to analyse how digital tools are utilised in urban co-creation. Five different cases are the units of analysis. What follows is an explanation of how the cases were selected and analysed using the framework.

Case Selection

The five cases analysed in this paper were originally submitted to the workshop "Co-creation practices and technologies for open urban planning" (Tellioglu et al., 2023), which took place at the 11th Communities and Technologies Conference in Lahti, Finland, in 2023. The workshop aimed to connect researchers and practitioners interested in co-creation practices, techniques, tools, and technologies for open urban planning. Specifically, the workshop drew on theoretical approaches from computer support cooperative work and from participatory design, focusing on engagement, participation and consensus-making in the context of urban

co-creation processes (Tellioglu et al., 2023). Participants were invited to submit position papers through a call for participation. Seven papers were selected for presentation in the workshop, including a scoping review on digital participation through ICT and a reflective paper on the challenges of co-creation processes in urban planning. The workshop took place in a hybrid mode, with three participants joining in remotely. The session lasted for a day and consisted of an introduction, followed by presentations of the different projects and a discussion round focusing on common challenges and approaches of the different cases. After the workshop, participants decided to systematise the common challenges and approaches in this paper. All participants worked collaboratively throughout this process. The five presented cases in the workshop, which represent projects of implementation of co-creation in urban planning that use digital technologies, were included. The other two papers (the scoping review and the reflective paper) were not part of the analysis but helped shape the background, context, and discussion of the case studies and results.

We are aware that there are many more projects which employ participatory approaches in urban contexts. Our selection of the five cases is strongly influenced by the projects submitted to the workshop. However, as in-person participation was not mandatory, this lowered the barrier to attending the workshop. The current case selection highlights diverse approaches to participatory urban planning, using different types of technologies, ranging time spans and urban scales, acknowledging the broader spectrum of ongoing projects in this field.

Data Analysis

The analysis of the cases took part in *four steps*, starting with the *selection* of the cases as illustrated in Figure 1. We excluded here the two workshop papers that did not consist of empirical findings, namely the scoping review and the reflective contribution which focused on challenges in co-creation processes. Input from these, however, was incorporated as part of the discussion. In a *second step*, the researchers re-read each other's contributions, to familiarise themselves with the entire corpus of data.

Thirdly, we considered potential frameworks for comparing the different cases, with a focus on the process, rather than the outcomes of the projects, considering these were very different in scope and duration. We settled on the Co-Design Framework by Gaete Cruz et al. (2023), as it focuses on how collaboration may occur in different steps of the co-design process. In mapping the five cases on the Co-Design Framework, we made two additions as outlined in Figure 2. Firstly, we colour-coded the activities, to clarify to what extent participation took place in a digital or analogue manner. Therefore, in the case descriptions, the colour-coded dots illustrate the characterisation as digital or analogue activity or both, where the size of the circle represents the proportion of each (see Figure 2). Secondly, where we conducted activities across two or more design cycles, we numbered these, to clarify which activities were part of the same design cycle.

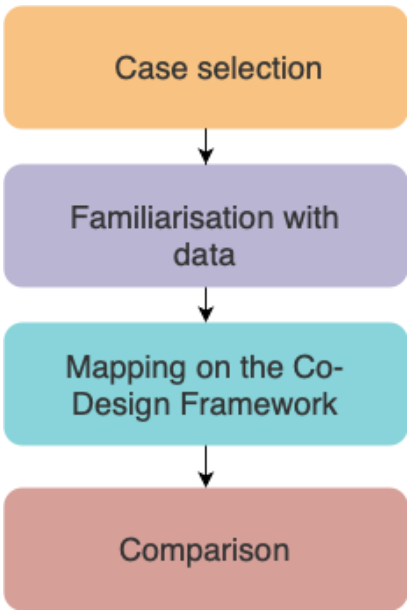

Figure 1. Process for the data analysis of the cases

Finally, *in a fourth step*, we compared the five cases to draw on insights resulting from the mapping of the Co-Design Framework. We simultaneously addressed to what extent the framework helps explain the cases and what are its limitations, while also looking specifically at the analogue-digital dimension, the types of stakeholders involved, and the temporality of processes and activities. These findings and reflections are illustrated in the results and discussion of the paper.

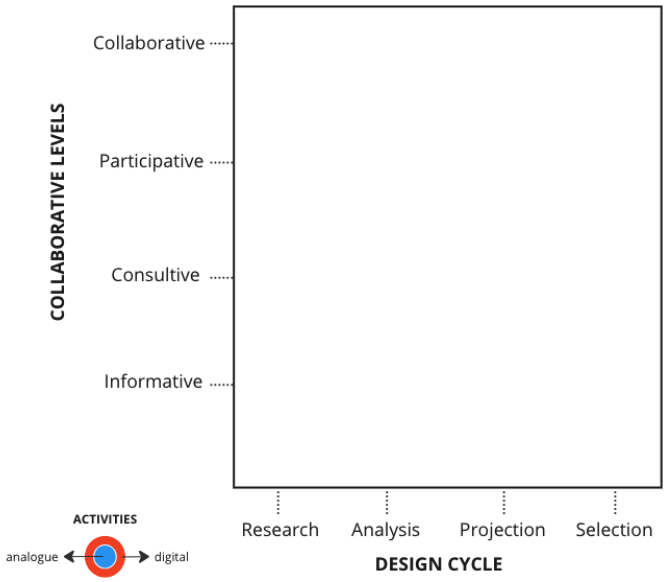

Figure 2. Co-design Framework by Gaete Cruz et al. (2023). The colour coding of analogue and digital activities is made by the authors.

RESULTS

Below follows a description and coding of the five cases Europe (Brussels, Munich, Rotterdam/The Hague, Vienna), Rotterdam (Netherlands), Salzburg (Austria), The Hague (Netherlands), and Vienna (Austria). All cases are contextualised through a brief case description. An overview of the activities is outlined in a table and mapped onto the Co-Design Framework. These mapping and its implications are further elaborated in the text.

SmartHubs Design Game - Europe

In the SmartHubs project, Design Games (Brandt & Messeter, 2004) are applied to identify stakeholder requirements, characteristics and wishes for smart mobility hubs. The application of Design Games follows two iterations, starting with an analogue Design Game, which is then transformed into an augmented reality (AR) supported Design Game in the second iteration. The game can be played by up to eight players, who design a specific area around a mobility hub and arrange elements, such as shared bikes, free WIFI, information kiosks, parks, etc., on the gameboard. The elements are physically realised as cards to be placed on the analogue gameboard. For the AR Design Game, prototypical smartphone apps were developed to enable augmented reality gaming support. Therefore, on each card, a QR-code is printed that is scanned by the app and the element is displayed on the smartphone screen. Figure 3 outlines the analogue and the AR game.

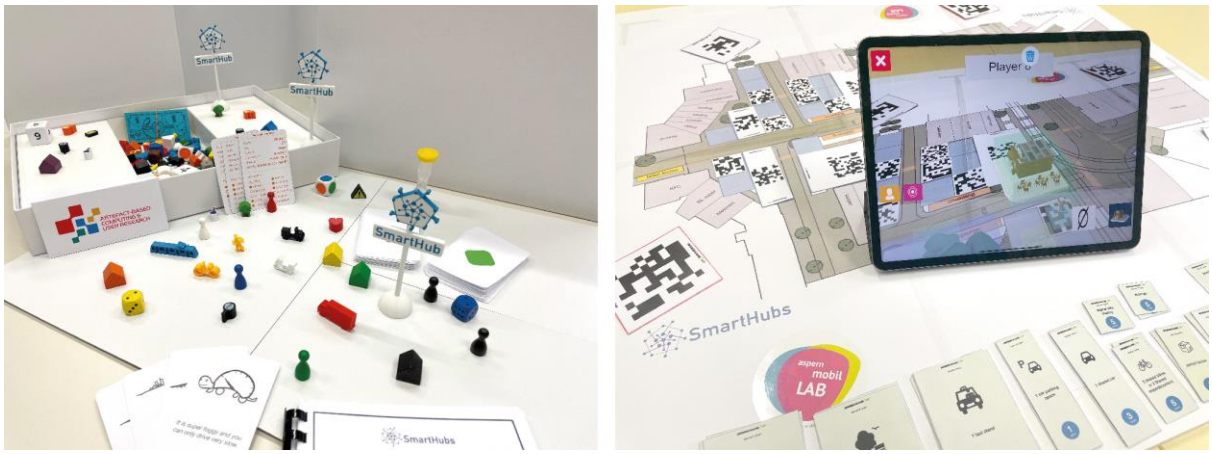

Figure 3. Analogue Design Game package with various materials (left) and resulting AR Design Game (right).

The SmartHubs project includes four living labs across Europe where different analogue games were designed and applied. For the design phase of the analogue game, the main stakeholders were the research partners from the project who run the living labs in Brussels, Munich, Rotterdam/The Hague, and Vienna. The application of the resulting games was realised with the stakeholders of the four labs, such as citizens, planners and municipalities. Both two design cycles included multiple activities in each stage of the design cycle axis and on various collaborative levels of the Co-Design Framework (Gaete Cruz et al., 2023). All

participative research activities are presented in Table 1 and time ordered according to their application.

Table 1. SmartHubs Design Game case at a glance.

TIME	Activity	Stakeholders	Analogue vs. digital
Aug. 2021	Collection of living lab profiles	TU Wien, living lab partners	Digital via cloud services
March 2022	Workshop for Design Game package and guide	TU Wien, living lab partners	Digital via online meeting including tangible objects
April, May 2022	Design support meetings	TU Wien, living lab partners	Digital via online meeting including tangible objects
From May 2022	Play testing of analogue Design Games	Living lab partners and living lab stakeholders	Analogue at the living lab location
June 2022	Design evaluation meetings (analogue Design Game)	TU Wien, living lab partners	Digital via online meetings
June 2022	Workshop for AR feature definition	TU Wien + feedback from living lab partners	Analogue in-person workshop and digital online meetings
Dec. 2022	Initial AR prototype tests	TU Wien, living lab partners	Digital (AR) and analogue (tangible game materials)
From March 2023	Play testing of AR Design Game	TU Wien, living lab partners and living lab stakeholders	Digital (AR) and analogue (tangible game materials)
March 2023	Design evaluation meetings (AR Design Game)	TU Wien, living lab partners	Digital via online meetings

Cycle 1

To get insights into the contexts of each living lab, lab profile templates were provided to be elaborated by all four living labs in the research phase of the first design cycle. In this activity, the research partners from the living labs were included on a rather consultative level. The structure of the templates was defined in collaborative project meetings together with the research partners. The resulting templates were shared digitally via cloud services and informed the Design Game process in a consultative way.

Based on the gathered information, sets with blank gaming materials were composed and sent to the living labs including a detailed step-by-step handbook, the Design Game Guide. After all packages reached the labs, a joint design workshop was conducted to introduce the materials and the guidelines to the living labs. This took place in the analysis phase of the design cycle as the living labs provided the first insights into the applicability of the package and the handbook. From the perspective of collaboration, these activities have been rather informative. The workshop was conducted digitally as an online meeting. Photos from the materials were presented on digital slides, though some research partners also used tangible objects of the package.

Further online workshops were conducted with each partner to continually support the design process. These workshops were used to assist the partners in creating Design Game

ideas, structuring the game flow and envisioning possible applications of the provided gaming materials in the package. Thus, these meetings can be classified as consultative, and they took place at the projection stage of the design cycle. The workshops were conducted digitally via online meetings, and again, tangible materials were used to present certain aspects of the game development.

From this first design cycle, one unique Design Game from each living lab resulted. The Design Games were play-tested in joint in-person meetings with all project partners and applied by the living labs with their stakeholders. This activity was conducted in the selection phase of the design cycle and is classified as participative on the collaborative level. The play testing activity was solely analogue, gathering players at one location to play the Design Games.

After the Design Games were applied, the design process of the living lab partners was evaluated in joint online evaluation meetings. Structured online meetings were conducted in the selection phase of the design cycle with all living lab partners to get insights into their design processes, the use of the provided material package and the guideline handbook. These consultative meetings clearly visualised the outcome of the analogue game design process but also informed the first phase of the second design cycle.

Cycle 2

In the second design cycle, the implementation of an AR Design Game was planned, using the game principles of the analogue Design Game from the Rotterdam/The Hague Living Lab as a basis for the implementation.

An explicit research phase was not needed at the start of this design cycle as the evaluation meetings from the end of the first cycle informed the second design cycle. The most relevant features of the AR Design Game were defined in the analysis phase of this design cycle in an internal workshop at TU Wien and communicated to the living lab partners digitally via informative online meetings and documents.

During the implementation phase of the smartphone apps, internal test sessions at TU Wien were conducted and the results were discussed with the living lab partners in online project meetings. Pictures and videos of the app and its functionality were presented, and feedback was gathered from the living lab partners. This activity took place in the projection phase of the second design cycle and was informative on a collaboration level. The AR app is a digital tool, but still some analogue gaming material, as the tangible gameboard and elements cards are used.

After the release of the app, in the selection phase of the design cycle, the AR Design Game was play-tested at in-person project meetings and applied by the living lab partners together with their stakeholders in participative sessions. Due to the characteristics of the AR Design Game, the playtesting is a mixture of digital and analogue activity. The AR Design Game itself is played in person using a gameboard and other analogue materials but enhanced by the digital AR layers.

As the final activity of the second design cycle, online evaluation meetings were conducted as part of the selection phase. Living lab partners provided structured feedback from the application of the AR Design Game in participative, consultative meetings.

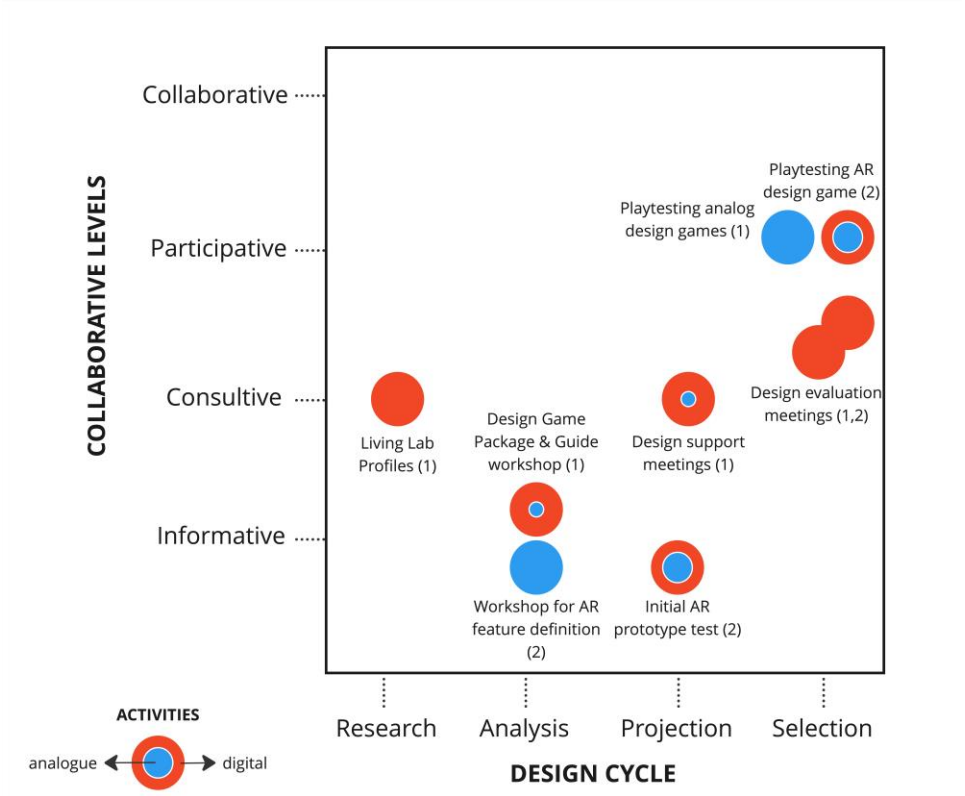

Figure 4. The co-design landscape for the SmartHubs Design Game. *Note for Figures 4, 6, 9, 11, and 17:* The colour-coded dots illustrate the characterisation as digital or analogue activity or both, while the size of the circle represents the proportion of digital and analogue parts. The numbers in the brackets refer to the design cycles.

In the development of the analogue Design Games and the AR Design Game, we managed to complete two full design cycles according to the co-design framework (Gaete Cruz et al., 2023). On the axis of collaborative levels, our activities reached the participatory level, where the games were played by the living lab partners with their stakeholders. The resulting Design Games as co-creation tools enable stakeholders such as citizens, municipalities, researchers and urban planners to meet in a common arena, debate and exchange their perspectives regarding the design of a smart mobility hub in an informal atmosphere the Design Game creates. On this level, Design Games provide valuable insights and ideas for planning future smart mobility hubs. As these stakeholders participate in playing the game, they provide their contribution, but as not all of them are included directly in the decision-making of smart mobility hubs, this activity cannot be characterised as collaborative.

Biodiversity Urban Living Labs - Rotterdam

The Biodiversity Urban Living Labs (BULL) case explores ways of co-designing "smart" data platforms and tools to engage citizens in supporting efforts towards local biodiversity. Given that most of the existing biodiversity monitoring tools are designed for expert users and most city space is privately owned, the BULL approach aims to engage residents in this urban transformation. The BULL approach should not only engage citizens but also lead to opportunities for individual and collective action towards biodiversity as a perceived common. The BULL approach is developed in collaboration with several stakeholders, the most important ones include a data-driven biodiversity foundation and a neighbourhood organisation. As this is an ongoing research project, only the two first design cycles are presented here, outlined in Table 2 and Figure 6.

Cycle 1

The first design cycle (for more information, see Slingerland & Overdiek (2023)) involved explorations and co-designing of various tools that support conversations with residents of a neighbourhood in Rotterdam (Netherlands) about neighbourhood green and biodiversity. This happened through pop-up activities, structured around a tea house that moved around in the neighbourhood for eight weeks at different locations. A constant reflection on the pop-up activities happened during community meetings with the main stakeholders. In the pop-up activities, multiple tools were tested, both analogue and digital ones. Therefore, this activity is mapped in multiple places on the Co-Design Framework and supports different collaborative levels with the residents who visited the teahouse. The digital tool tested was a sensor and corresponding platform which would provide suggestions on how to design your outdoor space based on the sensor's measurements. While this digital tool did not attract the interest of residents (while it was designed to be a collaborative tool), nor help them to talk about biodiversity, the opportunity map (see Figure 5) did support residents to co-create biodiversity hotspots and start negotiating about potential actions.

Cycle 2

The second design cycle aimed to create a digital prototype of this opportunity map since an analogue version requires residents to meet at a dedicated time and space and a facilitator to explain the table and structure the discussions. The first activities involved the interface design of the prototype and was created with paper sketches. Here, residents' opinions collected from the teahouse in cycle 1 were only used to inform this research. The paper-based prototype was tested with students, researchers, and industry professionals during a workshop (around 30 participants). Now, participants were consulted for their input and this was used to decide on design principles, so the selection stage of the Co-Design Framework (Gaete Cruz et al., 2023). Based on the collected feedback, ideas for improvement were generated by the design students and presented to the main stakeholders in a community meeting. In total, four community meetings were scheduled during the two cycles, mainly on the collaborative level, because in the meetings the researchers shaped the project together with the other main stakeholders, including the local community representatives. The

community meeting in which the platform design was discussed was on an informative level; however, input from the community is going to be collected during a neighbourhood festival scheduled in May. The organisation of the festival is mapped onto the collaborative level because this is truly a joint effort between researchers, the local community, and the other key stakeholders, as outlined in Table 2. The design was then further prototyped in a digital format using Figma software and is going to be tested during a conference in April 2024. Furthermore, a neighbourhood festival is organised in May 2024 where the digital platform to evaluate and design local biodiversity scenarios will be launched. Overall in the BULL project so far, the analysis and projection stages of the design cycle happen within the research and design team, and the participatory and collaborative activities have been executed to inform the selection stages of the design cycles. In the first cycle, though, the teahouse activities also allowed stakeholders to inform and consult the research stage of the design cycle. In that sense, the BULL activities until now follow a traditional human-centred approach, rather than a participatory one.

Figure 5. Opportunity map that allowed residents to co-create collective action towards more biodiverse green in the neighbourhood.

Table 2. Biodiversity urban living lab case at a glance.

TIME	Activity	Stakeholders	Analogue vs. digital
January 2022	Community meeting to prepare pop-up activities	Biodiversity foundation, neighbourhood organisation, researchers	Face-to-face meetings
February – May 2022	Pop-up activities, teahouse	Biodiversity foundation, researchers	In the neighbourhood, both digital and analogue tools at the teahouse
September – October 2023	Analysis of existing interfaces and platforms	Design students, researchers	Miro board and digital tools, discussions face-to-face
November – December 2023	Sketching interfaces of opportunity map	Design students, researchers	Analogue
January 2024	Prototype test	Students, researchers, industry professionals	Paper-based prototype
February 2024	Community meeting to present prototype and findings	Biodiversity foundation, neighbourhood organisation, researchers, design students	Paper-based prototype in a face-to-face meeting
April 2024 (planned)	Prototype test during conference	Students, researchers, industry professionals	Digital prototype in a face-to-face setting
February - May 2024 (planned)	Community festival, community meetings to prepare it	Biodiversity foundation, neighbourhood organisation, researchers, design students	Digital prototypes and analogue tools at a neighbourhood festival location

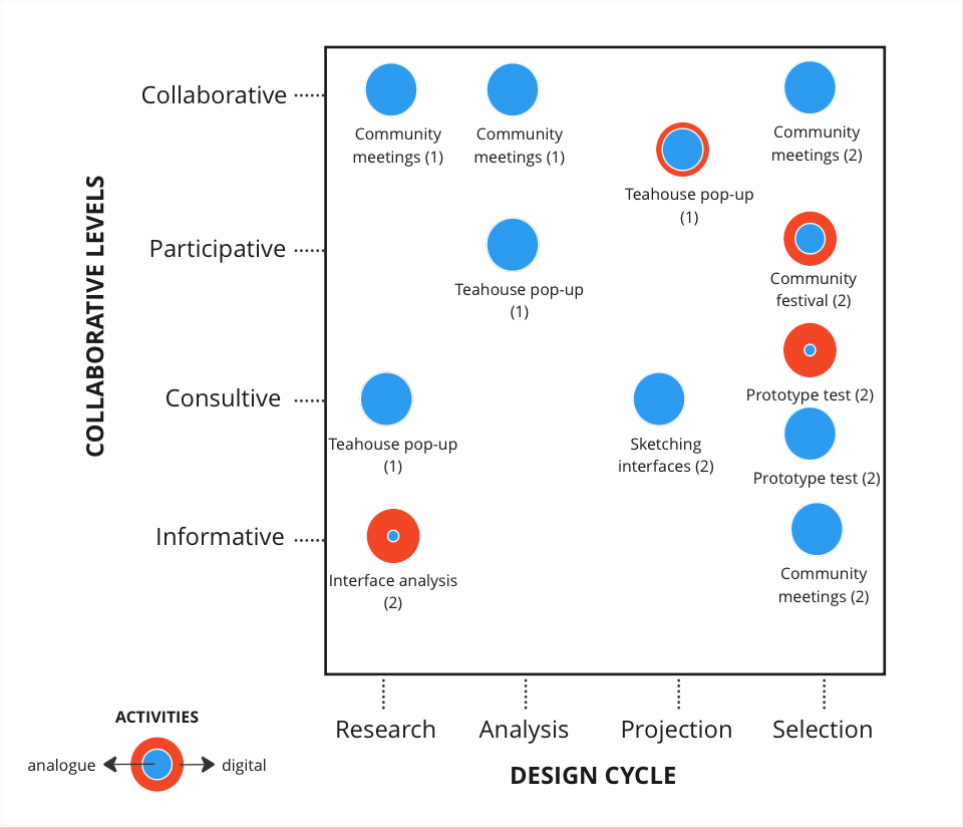

Figure 6. The co-design landscape for the BULL approach. Some activities have not happened yet and are only planned.

Speculative Futures in Salzburg

This work took place in a business district area in the city of Salzburg, which hosts a variety of technology companies, research facilities, university buildings, housing, and student dorms. The area had been transforming, with further interest in building housing units and potential redevelopment and relocation of some facilities. Moreover, while the area is compact, it has a limited number of amenities, such as eateries or outdoor seating spaces (see Figure 7).

The co-design process was led by the research team at the Center for Human-Computer Interaction at the University of Salzburg. The respective project team was especially engaged in digitalisation and public spaces. Throughout the activities described below, the researchers involved experts (architects and urban planners), representatives of city and regional institutions, residents, employees, and visitors to envision the future of this district. This resulted in two cycles of the co-design process (see Figure 9 and Table 3):

1. Creating futuristic visions of the district, using a speculative co-design approach.
2. Co-designing an augmented reality application called City Craft to support collaborative placemaking.

Figure 7. Science City Itzling, the location of the co-design activities.

Cycle 1

The first cycle focused on building futuristic visions of the district, starting from, and including technological developments researched in the facilities present in the neighbourhood. This process was mostly analogue, as it resulted in fiction created in the format of "Postcards from the Future." We opted for interviews with experts in the research and analysis phase, which focused on technologies relevant to the future of the built environment. Some interviews were digital, and some were analogue, depending on the location and time availability of experts. They directly informed the contents of the proposed fiction, as the results of interviews were analysed through affinity diagrams and were then translated into ideas for fictional postcards through ideation (Paraschivoiu et al., 2023).

We opted for pre-curating the fiction in the Projection phase, as some of the topics required an understanding of the underlying technology. The fictions were then used in two types of collaborative activities with a variety of participants: students, researchers, employees, visitors, and others. Participants took part in pop-up events and workshops, where they used the curated fictions as prompts to express their thoughts on a variety of topics such as the relationship between built environment, technology, and nature, or their hopes and fears about digitalisation in cities (Paraschivoiu et al., 2023).

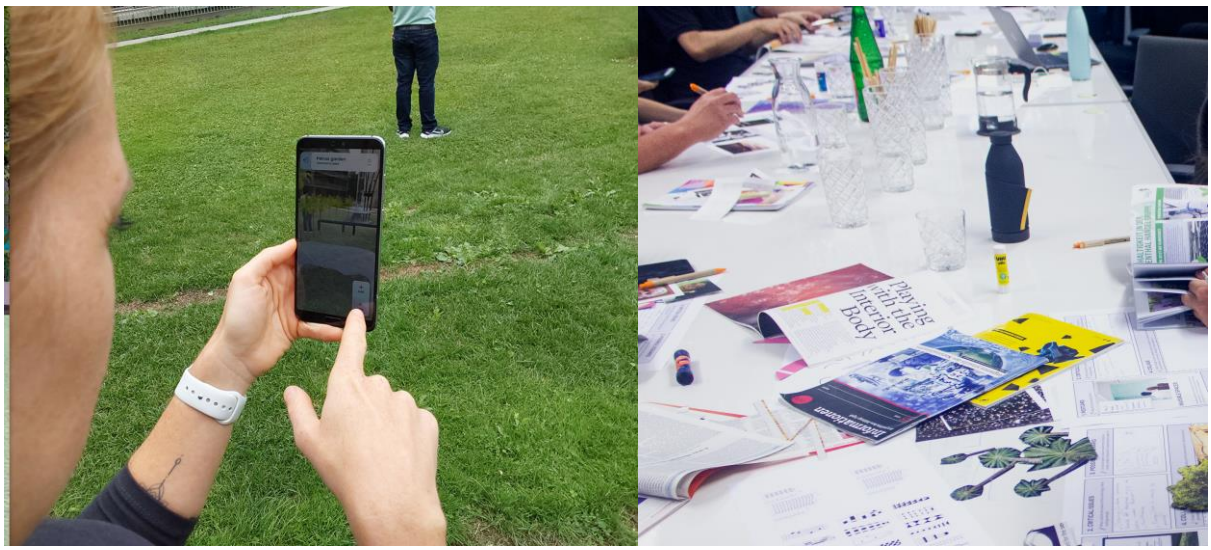

Figure 8. Co-designing with the augmented reality app (left) and speculative design workshop using analogue tools (right).

Cycle 2

In the second cycle, we addressed more specifically the topic of urban design and what kind of changes the community envisioned for it. To this end, we started the research and analysis phase with ten more interviews, with employees, residents, students, and experts. We specifically wanted to understand their cognitive mapping of the area, including their perception related to amenities, mobility, and urban furniture. This cycle included a more mixed approach to use of analogue and digital tools throughout the different activities.

The interviews again took place both in person as well as digitally, depending on the availability of interviewees. In addition to questions related to the site, we collected insights regarding the potential use of an augmented reality (AR) application, which resulted in an initial list of features and requirements. In the Projection phase, we involved 28 students in conducting ethnographic observations, noting down how the public space was used. The students then created 14 storyboards, illustrating their ideas for changes in public space and how these might be addressed through collaborative urban design.

The students themselves had freedom in how to collect their impressions and create their storyboards, resulting in some of them opting for hand drawings and sketches, while others used digital tools like Storyboarder.

These insights were further used to create a demo of the City Craft app, which was used in the first workshop. Citizens tested a version of the application with limited functionality, where they could place objects in public space and visualise and edit them. The interface had minimal onboarding, and testers offered input on interaction, user experience and design with City Craft. A click-prototype was also created. This was tested in single sessions in a walkthrough format, where researchers discussed with participants the application and its use in public space, following each functionality or step. Finally, we engaged 33 participants in workshops where they were invited to collaboratively design the urban space with augmented

reality. They could visualise and edit each other's designs and they also discussed their choices and which suggestions could be prioritised for implementation. The sessions concluded with a debrief discussion on the potential of AR for urban design and on their motivation to participate in participation processes related to the city.

Table 3. Speculative Futures in Salzburg case at a glance.

TIME	Activity	Stakeholders	Analogue vs. digital
September – October 2021	Expert interviews	HCI Salzburg, experts	Digital via online meetings and in person
December 2021	Ideation	HCI Salzburg	In person (analogue)
April – July 2022	Pop-up design fiction	HCI Salzburg, residents, employees, students, visitors	In person at different locations
July-September 2022	Design fiction workshops	HCI Salzburg, residents, employees, students, visitors	In person, workshop space at HCI Salzburg
March 2022	Interviews	HCI Salzburg, residents, employees, students, experts	Digital via online meetings and in person
April – May 2022	Storyboarding	HCI Salzburg, students	Sketching (analogue) or digital (different tools)
June 2022	Demo workshop	HCI Salzburg, researchers, digital experts	In person, using the AR app collaboratively on site
October – November 2022	Click prototype walkthroughs	HCI Salzburg, residents, employees, students	In person, using the click-through prototype, on site
April – September 2023	City Craft workshops	HCI Salzburg, employees, residents, students, architects, urban planners, city officials	In person, using the AR app collaboratively on site

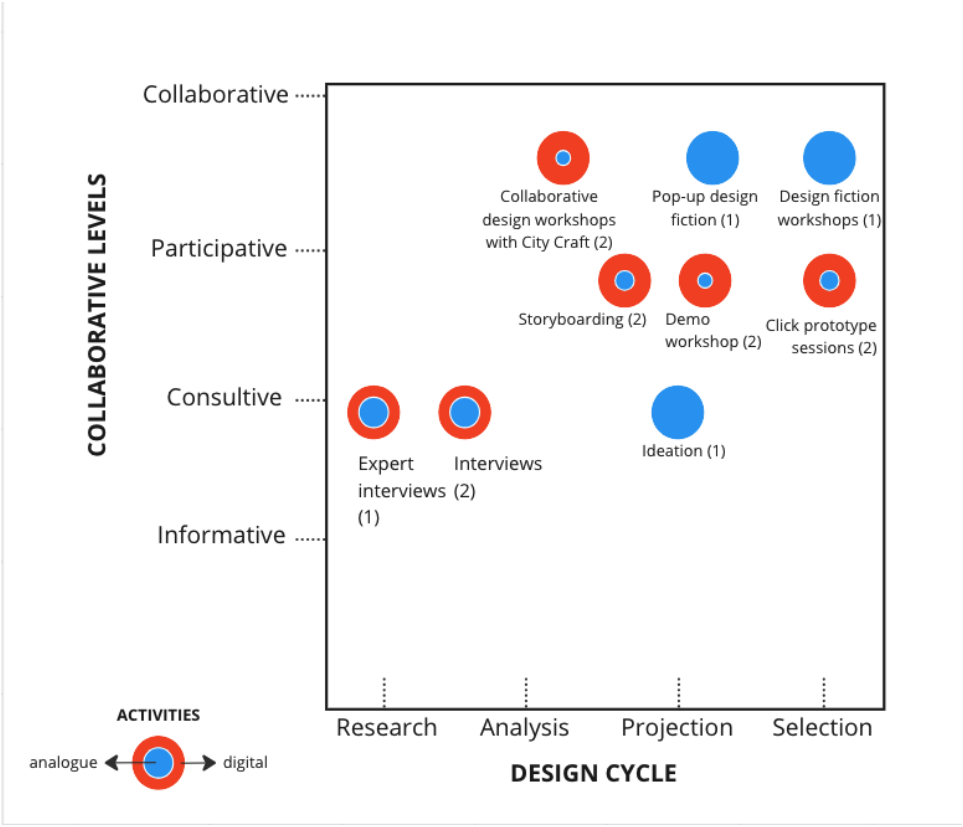

Figure 9. The co-design landscape for the Speculative Futures in Salzburg.

Location-based Game for Place-making – The Hague/Rotterdam

Location-based games are games that use technology to situate players in their location. The location to play the game is, therefore, a vital part of the gameplay. The location-based game Secrets of the South was developed in several cycles of which two are described here. The game is played with challenges, which are available depending on your location, and invite players to engage with the environment. The first cycle focused on evaluating challenge categories and the second on co-designing challenges. These two cycles took place over a period of two years (2018-2019). The activities are outlined in Table 4 and mapped onto the Co-Design Framework in Figure 11.

Cycle 1

The location-based game is an augmented-reality game and is played on a mobile phone. The first design cycle (for more detailed description, see Slingerland, Lukosch, & Brazier (2020)) took place in a neighbourhood in Rotterdam and involved children between 10-12 years old. Other stakeholders were a primary school and two local organisations. With these, two stakeholder meetings were held to manage expectations and exchange knowledge about the neighbourhood. To prepare the co-design workshops and playtests, the research team went on a neighbourhood walk with a local actor to get to know the area (informative level) and met with the school director and expertise actors to discuss what would work (and not) in terms of

co-design with children. These stakeholder meetings were on the collaborative level because a long-term collaboration was envisioned, and joint decisions were made on the scope of the research. The aim of this cycle was to co-create content for the game (the challenges). As a result, almost 50 challenges were designed by the children during the workshops (Slingerland, Lukosch, et al., 2020).

The design workshop and playtest happened during schooltime. Children went out in groups in the neighbourhood surrounding the school and were accompanied by researchers, who observed the children doing co-design and facilitated when necessary (see Figure 10). The children were debriefed at the end of the workshop. Mostly paper-based materials were used in the workshop, including an analogue camera. Mobile phones were used by children to interview each other and other residents. The challenge design workshop is mapped on the participative level, because the children were in the lead to design the challenges. In the design process, this activity informed the Projection stage, where idea generation takes place.

Figure 10. Children working on their challenge designs while walking around in the neighbourhood, supported by paper-based materials.

Cycle 2

The second design cycle (for a more detailed description, see Slingerland, Fonseca, et al. (2020)) took place in a neighbourhood in The Hague (Netherlands). Based on the challenges designed in the first cycle, researchers designed five challenge categories and corresponding challenges in preparation for the playtest workshop. This was a participative collaboration between the researchers only. In the workshop, residents of the neighbourhood played the game and were asked to evaluate the challenges and, specifically, the categories. This was a consultive activity to select the most engaging challenges. Here, digital technology (games on the mobile phone) was combined with analogue materials (the urban environment). In the follow-up workshop, residents designed their own challenges on paper and hence no digital technology was involved. During this workshop residents discussed their current experience of places with each other and envisioned what these places could or should be in the future

(Slingerland, Fonseca, et al., 2020). These two workshops deliberately mixed up the projection and selection stages of the design cycle, as it was assumed residents would design richer challenges after having played experience with the game.

Table 4. Location-based game for place-making case at a glance.

TIME	Activity	Stakeholders	Analogue vs. digital
November 2018	Neighbourhood walk	Neighbourhood organisation, researchers TU Delft	Walking is analogue, but shooting pictures and short videos
November 2018	Stakeholder meeting	Primary school, researchers TU Delft	Face-to-face meeting
November 2018	Stakeholder meeting	Field work organisation, researchers TU Delft	Face-to-face meeting
December 2018	Design workshops	Primary school, neighbourhood organisation, researchers TU Delft	Walking through neighbourhood with paper-based design prompts
December 2018	Challenge designs	Researchers TU Delft	Initial designs on paper, then programmed into the LBG
January 2019	Workshop 1 play testing	Researchers TU Delft, residents, community center	Playing LBG on mobile phone, situated in neighbourhood
January 2019	Workshop 2 challenge co-design	Researchers TU Delft, residents, community center	Paper, pens, sticky notes to design challenges

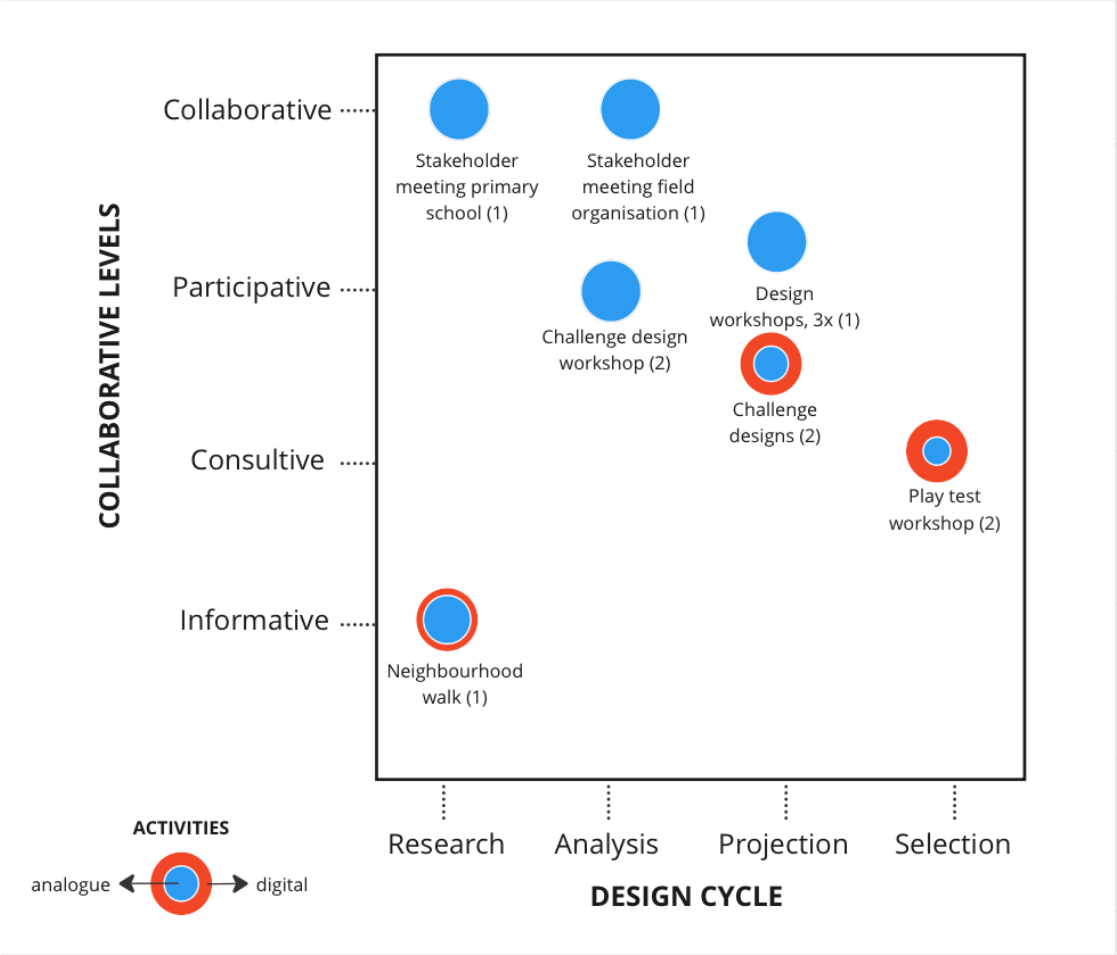

Figure 11. The co-design landscape for the location-based game for place-making.

The Co-Creation of a "Residential Street Culture" - Vienna

The following case study examines the co-creation of a "Residential Street Culture" (German: "Wohnstraßenkultur") – the legal use of residential streets by people. Since 2018, the Vienna culture and research organisation "space and place"[1] has been developing this specific street culture in Vienna in order to co-create new democratic and consumption-free social spaces in cities for all mobility participants – especially pedestrians. The project builds on the situation that consumption-free public spaces for people in cities are scarce. As stated in a recent article (Vettori, 2022), more and more green spaces in towns are being sealed, and many open spaces are being built. Social life on one's own doorstep has been displaced by the long-standing orientation of urban planning to the car-oriented paradigm (Knoflacher, 2013; Pfaffenbichler et al., 2018).

In 2018, "space and place" counted 179 residential streets in Vienna and decided to research the legal grey area of these streets in order to open up the public space "residential

[1] space and place, see https://spaceandplace.at/ (Retrieved at 03/03/2024).

streets" to people. In 2022, "space and place" already counted 225 residential streets in Vienna, which indicates a steady increase in this public space.

In this paper six design cycles (2018-2023) of this ongoing project are mentioned, each corresponding to an open-air season from around May to October in which activities were carried out. Not all activities can be described. Therefore, Table 5 contains brief information on the most relevant tools and is mapped on the Co-Design Framework in Figure 17.

Cycle 1 (2018): Use of Mainly Analogue Tools

In Austria it is not exactly regulated what non-motorised road users are allowed to do on residential streets.[2] They definitely are allowed to enter the residential street and play there. Cyclists may cycle in both directions. Motorised road users may enter and leave at 5 km/h, but not drive through. "space and place" in 2018 started with Participatory Observations[3] during walks on residential streets. It became clear that since the introduction of the Dutch concept of the Woonerf (Guttenberg, 1981; Kraay, 1986) as Wohnstraße in Austria in 1983, the concept had been conceived as a means of traffic calming but not as a place where pedestrians have priority by law: People did not walk or play on residential streets. The streets also were not safe: cars drove through; many of them faster than in walking speed. The police barely fined car drivers. Long learned behaviour led pedestrians to a uniform use of various streets: Most people walked on sidewalks even though it is allowed to walk in the middle of these streets.

Figure 12. The residential street "Zinckgasse" in Vienna is mainly used by drivers. Photo: Heidi Pein (2018)

In the first year of the activation of the Vienna residential street in 2018, "space and place" collaborated with the initiatives "Kollektiv Raumstation" and "geht-doch.wien" in order to examine the legal grey area of these streets and to develop the analogue tool "#residentialstreetlife" (German: "#wohnstrassenleben"): Furniture was put in parking spaces, residents and passers-by had the opportunity to make themselves comfortable: People sat on

[2] Cf.: Federal Chancellery of Austria (Bundeskanzleramt Österreich). Road traffic regulations § 76b (1960)

[3] The social anthropological method of "Participant Observation" is a field research method in which observers take on a social role in the target group under study and participate in their activities in order to document and subsequently evaluate what they perceive (Beer, 1999, p. 45).

deckchairs, stuck their feet in paddling pools, played chess or built furniture for the residential street. As a result, in September "space and place" declared the first "Day of the Residential Street" to celebrate this new "Residential Street Culture". While the activities on that day were carried out in consultation with the police, there was no need for preceding authorisation. It became clear that everyone was able to use the residential street spontaneously on a daily basis.

Figure 13. & 14. 1st "Day of the Residential Street" in the "Pelzgasse". Photo: Heidi Pein, 2018

The tests were evaluated and also discussed at a scientific conference.[4] "space and place" stated that the "Residential Street Culture" can only take off when at least four factors of the present situation would be improved: first, people need to be informed about what is allowed on residential streets; second, there need to be more safety on residential streets; third, residential streets could function as "oases of wellbeing" if the design of these streets would be improved and seating furniture would be placed there; and forth, the "Residential Street Culture" needs to be popularised.

Already in 2018, the factor "information" was enhanced, when flyers and alternative residential street signs were placed on streets during #residentialstreetlifes ("welcome on the residential street", "always nice and slow", "bring coffee"…) to draw attention to the residential street rules and to promote the new street culture. Also, an information film[5] was produced.

Cycle 2-6 (2019-2023): Use of a Mix of Analogue and Digital Tools

In the subsequent months, "space and place" further developed the tool #residentialstreetlife in co-creation with artists, architects, residents, and holders of small local businesses or institutions like schools. Together with "space and place", people held a picnic on "their" residential street, they read a book, visited cloths swapping and jam sessions. But they did not bring their own chair to set up a #residenitalstreetlife on their own - without the presence of initiators. In 2019, to achieve more awareness for the cause, "space and place" introduced further digital tools: In cooperation with Juan Carlos Carvajal Bermúdez from the Austrian

[4] Paper presentation at the Vanda-Conference in Vienna in 2018.
[5] "WIEN LEBT auf der Wohnstraße", space and place 2018.

Institute of Technology "space and place" developed an online "Residential Street Map"[6] for Vienna, which was implemented on their website and shows the locations of these 225 streets. And they created a "Residential Street Quiz"[7], where people can find out what is allowed on a residential street (Carvajal Bermúdez & König, 2021). Furthermore, the analogue tool "art.interview"[8] was developed, and the first cooperation partner (WiiR) organised a sports program on the residential street "Diepoldplatz" in the absence of "space and place".

In the outdoor season of 2020, because of the Corona pandemic, personal meetings were only possible to a very limited extent. "space and place" produced short social media videos showing how to use the residential street by oneself. The organisation also dedicated its work towards the factors "safety & place design": Two residential streets were painted with flowers. In cooperation with the program "Cool Streets" (Wien zu Fuß, 2020), the street was closed for three months; seating and tables were installed. Because the seatings were outdoors, they could be used by all age groups even during the Corona pandemic.

Figure 15. Street painting by
Julia Scharinger-Schöttel / space and place
Photo: Reinhard Gössel (2020)

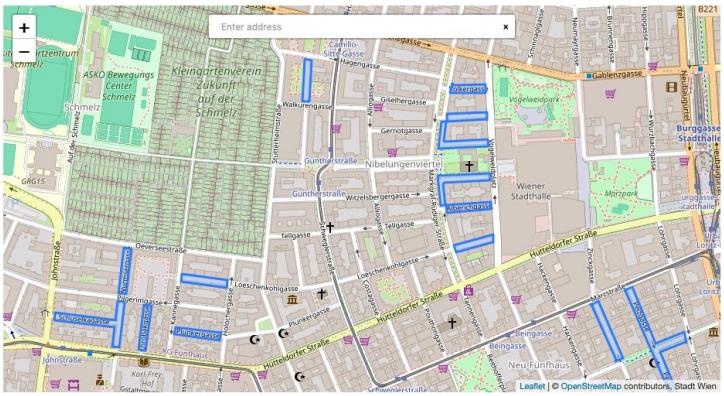

Figure 16. Residential Street Map,
See: spaceandplace.at/wohnstrassenkarte

In this very neighbourhood "space and place" 2020 also proclaimed the "First Viennese Residential Street Neighbourhood", which consists of seven adjoining residential streets in the area called "Nibelungenviertel" – understood as a new type of "Superblock". The centre was decorated for the first time with the temporary art installation "umbrella blossoms" by the architect Alain Tisserand. Neighbours and cooperation partners from "space and place" organised ten #residenitalstreelives there without "space and place" being directly involved. In another neighbourhood independent activities took place, too: the primary school

[6] See: https://spaceandplace.at/wohnstrassenkarte (Retrieved 03/03/2024).
[7] See: https://spaceandplace.at/wohnstrassen-quiz/ (Retrieved 03/03/2024).
[8] The tool from Julia Scharinger-Schöttel was presented on a residential street in Vienna in 2019 and - together with a paper on the topic (Brigitte Vettori) at the Institute of Politics in Bordeaux at the Interdisciplinary Symposium *„Well-Being in the North and South: Explorations, Contradictions, Power, and Practices"*.

"Gaullachergasse" declared the residential street in front of their school as a schoolyard for pupils. "space and place" had been celebrating a #residentialstreetlive there in 2018 and the school built creatively on these first experiences during the Corona period. Because of these experiences "space and place" continued to pass on their expertise of how to do #residentialstreetlifes also in outdoor workshops on residential streets. In 2021 – as the "Competence Centre for the Residential Street Culture" – the organisation also launched online-coaching to increase participation in the annual "Day of the Residential Street": As a result, up to 16 residential streets were activated on such a day independently from "space and place" by various actors in Vienna and Graz. At the same time, "space and place" also coordinated activities on three more residential streets in Vienna on that day.

In 2021 "space and place" continued to develop new analogue (city|tact) and digital (QR-walk) tools and – together with other stakeholders – set up an online and offline petition for this very neighbourhood "Nibelungenviertel", before in 2023 first improvements were realised. In 2023 "space and place" also got funded for the international EU-research project "StreetForum" which deals with the co-creation of analogue and digital tools for consensus-making in urban street transformation processes. Among other tools, the transferability of the tool #residentialstreetlife will be tested in Istanbul and Stockholm in 2024.

Table 5. The Co-Creation of a "Residential Street Culture" at a glance

TIME	Activity	Stakeholders	Analogue vs. digital
2018-2023	Participant Observation (cycle 1-6)	the researcher & the researched (drivers, pedestrians, cyclists)	anthropological analogue research method for self-reflexion
2018-2023	#residentialstreetlife (cycle 1-6)	residents; neighbours, holders of small businesses, institutions like schools, churches, kindergartens; co-operation partners like artists, architects, culture groups, activists; visitors; all people interested in the activation of residential streets; people from all ages, genders and backgrounds	analogue tool that can be combined with other analogue and digital tools
2018-2023	flyers (cycle 1-6)	drivers; residents; neighbours, people working on or near residential streets	friendly analogue information about the rules and regulations on residential streets & invitation to celebrate the residential street; other flyers with information on the topic or the programming of activities
2018-2023	alternative residential street signs (cycle 1-6)	drivers; residents; neighbours; people working on or near residential streets	analogue signs to be placed on easels in residential streets in order to draw attention to the street and to inform about rules and regulations & possible activities
2018	short film (cycle 1)	outdoor cinema-visitors	short film about the possible future use of residential streets
2018-2023	ideation and evaluation meetings	team "space and place"; cooperation partners; representatives of the City	analogue activity, also carried out digitally to a certain extent

	(cycle 1-6)	of Vienna; individual residents	
2018-2023	discussions with stakeholders (cycle 1-6)	residents; local experts; participants in discussions	analogue activity, with restrictions also possible in digital communication channels
2018-2023	scientific conferences (cycle 1,2,3,6)	scientists and experts	analogue activity, in exceptional cases online
2018-2023	PR (cycle 1-6)	local & national media and its readers	digital information about the #residentialstreetlife tool and the co-creation of a “Residential Street Culture”; analogue interviews
2019-2023	Residential Street Quiz (cycle 2-6)	anyone who wants to know more about the legal use of residential streets, including district councillors and other representatives of the city	digital tool, also used in analogue meetings or #residentialstreetlifes
2019-2023	Residential Street Map (cycle 2-6)	all people from Vienna who want to use a residential street	digital tool to help find residential streets in Vienna
2019	art.interview (cycle 2)	residents & people who want to share visions for the future of the residential street	analogue tool; images can also be used digitally in presentations
2020	short videos on social media (cycle 3)	people interested in the use of residential streets during the Corona pandemic	digital tool to foster the analogue “Residential Street Culture”
2020	street painting (cycle 3)	financial partners supporting the authorisation of street painting; partners such as district heads and various departments of the City of Vienna; artists; residents; neighbours; visitors	analogue street activity: paint a street with a semi-permanent paint which lasts for several years.
2020-2023	umbrella blossoms (cycle 3-6)	all residents; neighbours; visitors of a place where the temporary art installation takes place	analogue tool made of (recycled) umbrellas to raise awareness for a place or street
2020-2023	workshop “Making of #residentialstreetlife” (cycle 3-6)	interested residents; multipliers from art and culture or city-related organisations; students from various universities in Austria and abroad	analogue tool to learn hands on how to organise a #residentialstreetlife; also carried out as a walk
2020-2023	online coaching for the organisation of the annual “Day of the Residential Street” (cycle 3-6)	interested residents in Vienna and other cities; local organisations or holder of small businesses who want to implement a #residentialstreetlife on the Day of the Residential Street	digital tool; two to three preparation meetings before & one evaluation meeting after the activity, which is realised independent of "space and place”
2021-2022	QR-Walk in the “First Viennese Residential Street Neighbourhood” (cycle 4-5)	anyone interested in visiting this neighbourhood; especially people living in the area and passers-by	digital tool that informs about the history of this “Residential Street Neighbourhood” and interesting people living or working here; about activities which can be done on residential streets
2021-2022	city|tact (cycle 4-5)	musicians, residents, neighbours, passers-by, people interested in art & culture	music rehearsals (in contrast to notifiable concerts) on a residential street

2022-2023	petition for a better quality of life in the "First Vienna Residential Street Neighbourhood Nibelungenviertel" (cycle 5-6)	residents & other people who are interested in the neighbourhood or the promotion of the "Residential Street Culture" and want to sign a petition	analogue and digital vote collection; information dissemination through flyers, online information, hearings in the petition committee and the respective district
2023	various consensus-making tools (cycle 6)	people & neighbours involved in two specific living labs in Vienna and residential streets as part of the interdisciplinary EU research project StreetForum (residents, pupils, community gardeners, holder of small businesses or cafés, city representatives, district councillors)	analogue tools which foster consensus making between different stakeholders in the project area; will be combined with digital tools in 2024/2025

All these tools and activities, as well as the ongoing research and networking, have been contributing to progressing and diversifying the culture of residential street life. Because of public relations and social media work, the topic also gained popularity in the local and national media.[9] The analysis of this case study shows that the analogue tool #residentialstreetlife, which can be seen as rooted in the field of "tactical urbanism" (Lydon et al., 2015), is the most central to raising awareness for the "residential street culture" and to foster a common understanding of the manifold possibilities of using these streets as a social public space. "space and place" used the tool nearly 80 times from 2018-2023, and other residents and cooperation partners have started to organise #residentialstreetlives on their own.[10]

The Co-Design Framework below, which is extended to the "collaboration level" with the category "self-determined", shows that, in general, analogue tools dominate at the "participatory" and "collaborative level", while groups of mixed approaches can be identified at the "informative" and "consultive level". It becomes clear that analogue and digital tools support each other in a design circle from "research" to "selection" - or as put in the Figure from "research" to "implementation & evaluation". The tool #residentialstreetlife is especially being supported by digital tools such as the "residential street map" or the "online workshops". Because in Austria, residential streets can be used spontaneously without any further permission, it is possible to reach the highest level of participation in the activation of the residential street – namely, the "self-determination" of the users (Bliss, 2009)[11]. This is why residential streets can be described as consumption-free, democratic social places in the city that residents may create for themselves.

[9] See: https://www.spaceandplace.at/presse (Retrieved 03/03/2024)

[10] See.: Initiative "Goldschlag 33" (https://www.goldschlag33.wien/, retrieved 03/03/2024), "Wohnstraße Kollmayergasse" (https://wohnstrasse-kollmayergasse.at/, retrieved 03/03/2024) and "geht-doch.wien" (https://geht-doch.wien, retrieved 03/03/2024)

[11] Frank Bliss (2009) has explained the "stages of participation" in connection with participatory measures in development planning. They are also relevant in urban work and research.

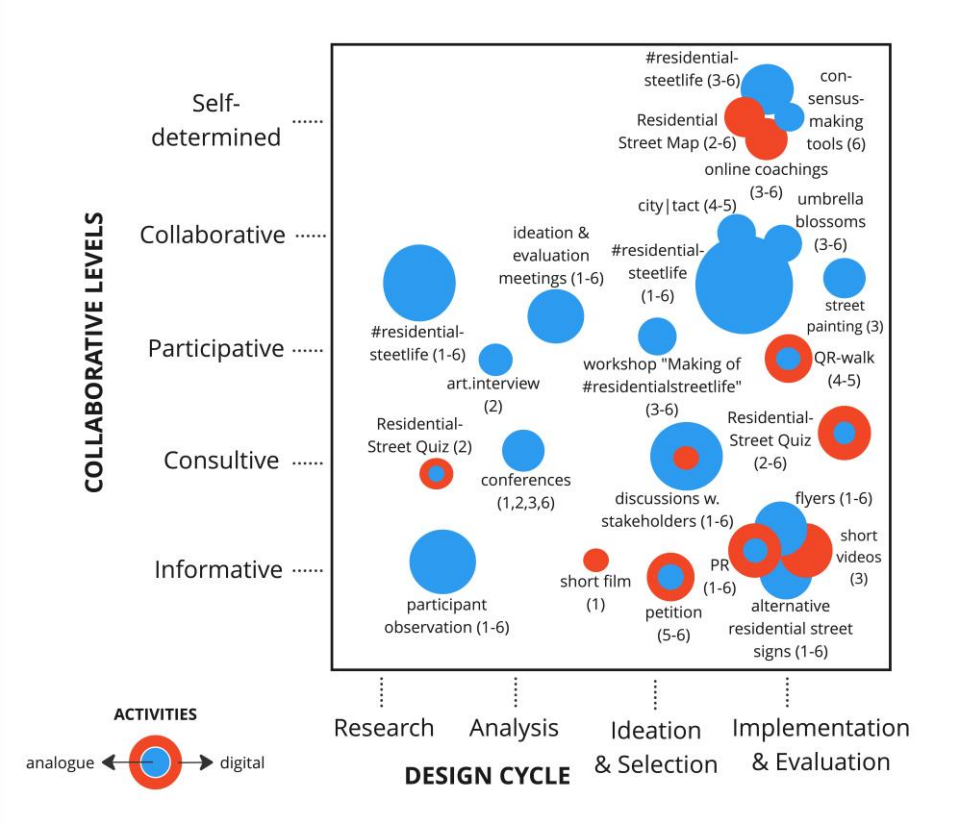

Figure 17. The co-design landscape for the Co-Creation of a "Residential Street Culture".

DISCUSSION

Five different types of urban co-creation were analysed in this paper using an adapted version of the Co-Design Framework (Gaete Cruz et al., 2023). The first purpose was to use the framework to untangle and articulate how digital and non-digital practices co-exist and coincide in urban co-creation practices. The second aim was to see whether this framework is useful for comparing co-design case studies that are hugely varied in timespan, spatial scale, stakeholder involvement, and number of collaborative activities. This section will discuss when and how digitalisation occurs in the design cycle of urban co-creation processes (purpose 1) and which insights can be gathered by comparing our cases through the Co-Design Framework (purpose 2).

The Role of Digital Technology in Urban Co-creation

All five presented cases of urban co-creation use digital technology through all the stages of the design cycle. However, the number of activities that include digital elements varies amongst the cases, ranging from the "Co-Creation of a Residential Street Culture" case initially using a lot of analogue-based activities, to the SmartHubs case using digital technology right from the start. It is, however, questionable whether introducing technology early in urban co-creation is the most suitable approach. Not only are designers and researchers used to designing, organising and applying analogue packages and tools (such as cultural probes (Mattelmäki, 2008)), but participation is always about getting in contact with other people (Baibarac & Petrescu, 2019; Webb et al., 2018). Transforming this process and tools into digital services affords high effort, knowledge and testing to achieve a certain quality in the results. Why transform well-working analogue methods and tools into digital versions? The experiences in four of the cases (Smarthubs, Speculative Futures, Place-making game, BULL) illustrated that digital technology in urban co-creation can distract from the collaborative process because the technology is buggy and users are unfamiliar with it. This resonates with findings from others (Vrebos et al., 2023) who have experimented with using digital technology in urban co-creation.

According to Harris (2002) (see also (Baibarac & Petrescu, 2019; Pokharel et al., 2022)), collaborative and participatory processes are complex. At the start, time needs to be invested to get acquainted, build trust, and align expectations of the collaboration (Innes & Booher, 2004). Such a process can be facilitated by technology, as the cases in this paper have shown, but it needs to run smoothly. Analogue methods appear to be easily applicable and used by participants because the majority are familiar with simple tools like paper and pencil, diaries and even photo cameras. However, participant's experiences with digital tools can be way more varied, because people use a great variety of apps, services and devices. Someone who is familiar with an Android phone perhaps cannot easily switch to an iOS device and vice versa. People are familiar with social media, e-mail applications, calendars, note-taking apps, etc., they are using on a regular basis, and not everyone is using the same tools. This makes it difficult for researchers and designers to develop digital methods everyone can work with easily without putting unrealistic effort into it. In contrast, the case of the "Co-Creation of a Residential Street Culture" had a more incremental approach to introducing technology into the collaborative process, and, for a great part, used existing tools and platforms that residents are already familiar with. This provides more support for participants to start initiating and continuing urban co-creation activities because they are not dependent on buggy technology developed by the researchers.

Does this discussion then lead to the proposition to stop developing digital technologies for urban co-creation? Alternatively, we suggest that more is to be learned on how urban co-creation technologies should be designed to better facilitate the various stages of the design cycle. Consequently, the next two sections look more deeply into the design cycle stages of the Co-Design Framework and how digital technologies can support collaboration throughout the design process.

Required quality of material in design cycle stages

The Co-Design Framework distinguishes four stages of the design cycle: research, analysis, projection, and selection. Each stage may require different kinds of facilitation, whether through analogue or digital tools. None of the presented cases uses only digital tools in the first stages; they always seem to start with analogue or at least a mix of digital and analogue. Our analysis suggests that using only digital tools hinders getting participants or communities onboard of the urban co-creation.

The Design Game, using AR, developed in the SmartHubs case completed two full design cycles according to the Co-Design Framework. In each design cycle stage, digital tools were used, sometimes together with analogue ones. Two perspectives are relevant to discuss about this case. The first perspective addresses the design process of the Design Games themselves. Here, digital tools such as online meetings and cloud services are highly supporting the process. Since the COVID-19 pandemic, people have used these tools, and collaboration through digital tools in the project worked well. The second perspective addresses the Design Game as a co-creation tool. Here, the process showed that designing and realising analogue high-quality material, such as the gaming material package, needs much effort, but digital material affords extensive work and effort to reach a level of quality where users can easily handle the material. Analogue gaming material can easily be adapted or recreated, whereas adapting the functionality of an app requires expert knowledge in software development. However, when the analogue game was being augmented with AR, the activities merely took place on an informative and consultative collaboration level. It seems that the increased digitalisation of the AR Design Game is providing a more rigid and less collaborative approach to urban co-creation. The digital version of the game is excellent to collect input, inform residents, and gather feedback, but less so for creative exploration, idea generation, and including residents in urban decision-making.

AR and other types of digital technologies can help stakeholders explore alternative perspectives to the city, which could support greatly the research and analysis stages of the design cycle, as illustrated in the Salzburg, BULL Rotterdam, and SmartHubs Europe cases. However, the cases in this paper that used AR, as well as others, noted that participants spend a great degree of effort getting accustomed to and configuring the technology (Wilson et al., 2019). Developed technology, especially those still in a prototype stage, may lack usability and most stakeholders are not lenient with prototypes. As a result, participants get distracted by figuring out how the technology can be used instead of focusing on discussing the issue at hand. This was also observed in the location-based game case, when playing the game with adults in The Hague. Particularly, in the analysis and selection stages of the design cycle that include decision-making, such type of distracting interactions are not helpful. However, as digital tools reach final stages of implementation and provide flawless user experience, they can support participants' creativity and even foster a collaborative mindset. For example, in the final workshops using the City Craft app in Salzburg, we found that most participants worked together in a collaborative way and reported an increased interest in participating in urban design, after the workshops.

In sum, (digital) tools to support urban co-creation can be varied according to which stage of the design cycle they are used. In the initial stages, or perhaps in the whole first iteration, when stakeholders are building trust and starting up the collaboration, digital co-creation tools are perhaps not the best choice. If one wants to collaborate and co-create with

digital technologies, such as the AR tool to speculate futures, onboarding to the technology as well as usability needs to be considered in designing this process.

Attending to temporality in hybrid and digital co-creation

Besides a deliberate selection of a tool in relation to the design cycle stage, another essential component to consider is the timespan of the collaborative activities. There is a huge contrast between activities scheduled in a workshop setting and pop-up activities such as in the BULL case. Workshops assume that participants reserve dedicated time, for example, two hours, to join in and engage in the collaborative activity. This provides room for onboarding, joint exploration of technologies, debugging and getting acquainted with digital tools or prototypes. A pop-up setting, such as the mobile teahouse in the BULL case, leaves less time for that because participants will serendipitously join the activity and often engage for only a few minutes. Similarly, the "postcards from the future" employed in Salzburg enabled participants to engage in a pop-up setup with highly complex topics such as novel interactive materials in built environments. Introducing prototypes in this setting does not work well because participants are not prepared for it and are not willing to take the time to be onboarded to the prototype. Often, these pop-up activities are set up in public and transitional spaces, where participants can engage "on the way" and are only available for a limited amount of time.

The component of time is related to the previous discussion on the quality of the materials in urban co-creation. Developing high quality materials requires a lot of time, but users can then apply the tool quickly without intensive training or onboarding. Developing analogue tools with the same kind of usability is less time-consuming and, therefore, seems to remain the preferred option, especially in pop-up and short urban co-creation activities. This component of time is a rather prominent differentiator between digital and analogue tools and is currently not explicitly outlined in the Co-Design Framework, while it has been marked as an important requirement for co-creation by others (Evans & Terrey, 2016).

These reflections support drawing up the following propositions on the role of digital technology in urban co-creation:

- Trust building and stakeholder familiarisation processes in the first stages of urban co-creation are best supported by analogue co-creation tools and activities.
- Using digital tools in urban co-creation runs the risk of participants getting distracted by technology flaws and bugs, hindering the co-creation process.
- Collaboration and co-creation with digital technologies are possible and engaging but require proper onboarding of participants and high usability standards.
- The temporality of the urban co-creation activities is a prominent factor in selecting digital or analogue tools; digital tools should only be used in pop-up or short activities when no onboarding is required.

Reflection on using the Co-Design Framework

In the context of this paper, the five case studies discussed were mapped to the Co-Design Framework that combines the collaborative levels of the citizen participation ladder of Arnstein (1969) and the design cycle (Roozenburg & Eekels, 1995). In principle, the

framework was helpful in mapping the urban co-creation activities of all the five case studies. Notwithstanding, some adjustments were made to the framework for a clear demonstration of the individual activities their temporal components and for untangling the level of digitalisation of the mapped activities. The colour-coded dots in our graphics illustrate, for example, the characterisation as an analogue tool (blue dots) or digital tool (red dots) or as both (blue dots with red circles). In addition, the size of the dots and circles differs depending on the proportion of digital and analogue parts of an activity. Finally, assigning numbers to the activities that refer to the respective design cycles allowed us to track how activities were digitalised or became analogue throughout multiple iterations.

In general, the framework can support but not replace a qualitative description of the approach: for example, it is necessary to understand to what extent socio-cultural factors like the COVID-19 pandemic influenced the progress, as well as the availability of funding and personnel resources. In our case descriptions, which were reviewed by all authors, we also took into account other socio-cultural and climate factors which influenced the projects in general. We find that these also need to be described. Together with a qualitative description, the framework may visually point out certain tendencies of the process described and how the interconnection of analogue and digital tools may support the various levels of collaboration.

CONCLUSIONS

Cities and local governments are increasingly involving residents and other urban stakeholders in the design of the city. This so-called participatory turn in urban planning has recently been further strengthened by the use of digital technologies, to open up co-creation practices to a wider variety of participants as well as to enable exploring potential futures together and creating a common understanding. In this paper, five cases of urban co-creation were mapped on the Co-Design Framework (Gaete Cruz et al., 2023), to untangle how this collaboration was shaped and which role digital technology took in it. This analysis served two purposes: first, to generate insights into how and when digitalisation supports urban co-creation, and at which stages of the design cycle analogue methods are to be preferred. Second, to explore whether this framework is useful to compare and contrast cases that vary from each other in terms of utilised tools, spatial scale, and timespan.

For the first purpose, our findings illustrate that in the initial stages of the collaboration, digital tools may be too distracting and not supporting to build rapport, trust, and common goals. Digital tools that are in a prototype stage, which often is the case in research projects, can be more difficult to use in a meaningful way because they are buggy and participants are not used to working with prototypes. Therefore, our suggestion is to consider usability needs as well as onboarding to the technology as essential elements when introducing digital tools in urban co-creation.

For the second purpose, our conclusion is that the framework is general and specific enough to map all of the selected cases and to compare them to each other. However, not all the terms of the design cycle (research, analysis, projection, selection) were considered to grasp the meaning of the activities; thus, one case adjusted two of the terms to better fit the case. Furthermore, the same case also added a level of collaboration that was deliberately left out by the authors of the Co-Design Framework, yet was needed to fully grasp the “Co-

Creation of a Residential Street Culture" case. Finally, the component of time is currently not visible within the framework, while in all five cases, this was an essential component to compare when certain activities happened, how they informed the next ones, and how both knowledge and the design were built through time. Our suggestion is to include the component of time, for example, using numbers to differentiate iterations as we did in the case descriptions.

This paper was strongly informed by discussions held during the workshop "Co-creation practices and technologies for open urban planning", which took place at the 11th Communities and Technologies Conference in Lahti, Finland, in 2023 (Tellioglu et al., 2023). Therefore, the research and analysis have been shaped by the cases that were brought to the workshops and the workshop participants. However, since the cases differ from each other on various characteristics as discussed before, we consider this analysis still meaningful to explore the Co-Design Framework and the usage of digital tools in urban co-creation. The analysis presented in this paper, as well as the insights on digitalisation in urban co-creation can be picked up by others to 1) inform the design of future digital tools that are to be used in participatory urban planning, and 2) analyse their own cases using the Co-Design Framework to build the body of work on how collaboration works in urban planning and what is the role of digital technologies in urban design practices.

IMPLICATIONS FOR RESEARCH

We are increasingly living in a hybrid world where participation occurs in both physical and digital spaces. Digital tools for co-creation offer new opportunities for involving various stakeholders in city-making, but there are no one-size-fits-all solutions. In line with our findings in this paper, we suggest future research should investigate how hybrid tools and practices may be further employed in urban co-creation processes, enabling citizens to participate both remotely and on-site in the early and late stages of design. How can novel technologies like AR support analogue tools and be embedded into long-term community-building and empowering processes? This question is also addressed in an ongoing international EU project "StreetForum", in which several of the authors are involved: Digital and analogue tools are being further developed to promote sustainable consensus-building processes in the context of street transformation. The transferability of selected tools will be tested in Brussels, Istanbul, Stockholm and Vienna until 2025.

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ON DESIGNING SHAREISH, AN OPEN-SOURCE, MAP-BASED, WEB PLATFORM TO FACILITATE DIVERSE SOLIDARITY PRACTICES

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Abstract: *We present the Shareish web platform to foster diverse solidarity practices inspired by concepts of the gift economy. Its design is grounded in prior work (in CSCW and solidarity HCI), and in new qualitative research involving participants engaged in solidarity practices. Shareish aims at leveraging community assets through donations, free loans, requests of goods and services, free event announcements, and by enhancing the visibility of freely available resources. On a Shareish instance, users have the ability to view localized items on a map or in lists, utilize search filters, contribute new content with detailed textual and visual descriptions, engage in discussions with other users, and receive notifications when new content is added in their neighborhood. The platform can be replicated and improved by communities seeking autonomy as its source code is distributed freely under a permissive open source license (https://github.com/shareish). A research demonstration server is available (https://shareish.org).*

Keywords: *solidarity HCI, mutual aid, gift economy, online web application, free open-source software.*

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INTRODUCTION

The modern era is facing worldwide population growth, resource depletion, unequal access to resources, extensive pollution, and significant waste across various sectors like food, textiles, and furniture. Moreover, it continually confronts substantial crises on a large scale, encompassing floods, conflicts, pandemics, storms, and economic crises or recession downturns. Diverse global and local endeavors are conducted to mitigate or restructure how we produce and consume (exemplified by initiatives like the "sharing economy," "circular economy," and "zero-waste" movements), alongside efforts to enhance citizen participation in decision-making processes.

The Sharing Economy and Alternative Networks

At the beginning of the 21st century, the emergence of digital technologies and of the Internet held the potential to facilitate collaboration among individuals and the shared utilization of their resources via the sharing economy (Schor & Vallas, 2021) where individuals grant each other temporary access to under-utilized physical assets (leveraging the “idling capacity”). It has been argued that the sharing economy could reduce overconsumption, better redistribute resources, and mitigate the continuous growth of climate emissions (Pérez-Pérez, Benito-Osorio, García-Moreno, & Martínez-Fernández, 2021). Indeed, similar objects to those that can be purchased new might be underutilized by neighbors who acquired them previously. Similarly, it is not uncommon for an organization to own a specific equipment that it under-utilizes while other organizations struggle to find such equipment for a one-time event. Likewise, this latter organization might have another equipment that could be beneficial for the former entity. In terms of food, stores or neighbors might have surpluses e.g. when the purchase or use of food does not go as planned, or when there is an abundance of personally grown fruits, plants, or vegetables. Technological artifacts or platforms from the sharing economy and smart cities concepts have then been promoted to optimize cooperation, co-use and reuse, of physical assets. However, scholars have argued the transformative potentials of these technologies should be questioned. More than ten years after the onset of the digital sharing economy (Miguel et al., 2022), it is obvious that social networks and such sharing platforms significantly ease the sale of (used) objects (e.g., via Facebook Marketplace or Vinted), the renting of physical assets (e.g. apartments through Airbnb or various tools through the Library of Things) or the access to various paid services (e.g. rent a scooter or taxi driver through Uber). Although these web platforms are undoubtedly useful for people who can afford to pay for sold items and services, these online tools do not profoundly change the way we produce, consume, and organize social relations. For example, according to a critical assessment of the sharing economy in Europe (Česnuitytė et al., 2022), food supply through existing ICT sharing platforms (e.g. to use food surplus) "hide from consumers negative outcomes such as precarious jobs, unfair labor practices, generating overconsumption, and hiding ecological externalities". In fact, many existing sharing platforms were not originally designed with equity or social justice in mind (McLaren & Agyeman, 2015), they promote commercial transactions (Belk, 2014), and the interactions facilitated by technical and design choices of these systems are claimed to be only a variant

of the market-based economy principles (Martin, 2016). These platforms have been very apt at "sharewashing" (Hawlitschek, Stofberg, Teubner, Tu, & Weinhardt, 2018) or adopting and exploiting the language of non-monetary practices by transforming these interactions into for-profit business.

Hence, alternative approaches and technologies that enhance the visibility and efficiency of sharing in fair and sustainable ways could be highly beneficial (Carroll & Bellotti, 2015; Light & Miskelly, 2019; Jiang & Marjanovic, 2021; Soch et al., 2022). Designers may find numerous off-line initiatives that try to address the aforementioned issues and to offer more inclusive alternatives to be of significant interest. Local exchange trading systems (LETS) and timebanks are networks of individuals willing to share local goods and services using alternative or complementary currencies (Seyfang & Longhurst, 2013; North, 2017). Such initiatives exist across various regions of the world. Although beneficial for participants, these initiatives still remain relatively niche, as they only involve a small portion of the population, and the general public is not well aware of the resources available. Potential free goods and services could remain entirely unnoticed by potential recipients and unshared by donors if these individuals are not engaged in these networks which may occasionally impose criteria for access. In an effort to improve this situation, online interactive systems have been designed to facilitate such exchange of goods and services, yet they come with various drawbacks and limitations. First, some of these online platforms may require subscription fees or target specific geographical audiences (e.g. a city or a country) because they are managed by a single entity (a company or organization) which has limited resources. Consequently, numerous communities are not the intended recipients of these platforms, leaving many individuals without the opportunity for easy exchange with others in their neighborhood. Moreover, these platforms often implement a "virtual currency" exchange system so that when a user offers an item (good or service) they can accumulate units of this currency which they can then use to barter, i.e. to later request a service or a good from others. However, such bartering (called “pseudo-sharing” by (Belk, 2014)) can potentially lead to exchanges motivated by accumulation and speculation hence somehow result in unequal access to resources, as goods and services are still exchanged for value received. Importantly, the use of a (virtual) currency might also sometimes dissuade people from participating. Since determining the value of a good or service is not straightforward and relies on many factors, this can complicate and limit exchanges. Furthermore, individuals may not always be aware of what they can offer in return. Therefore, bartering could dissuade especially those in need who currently lack anything to exchange. Furthermore, bartering or timebanking does not sound ethical nor desirable in acute crisis situations (such as a flood, war, pandemic, storm, economic crisis or recession,...), and one might argue quantifying and monetizing voluntary action somehow eliminates its autonomous aspects by denying to people the possibility to give altruistically (Wilson-Thomas, 2015) or by discouraging them from performing random acts of kindness (Bellotti, Carroll, & Han, 2013) which generally have positive impact for all involved parties (Curry et al., 2018; Kumar & Epley, 2023). It can also be argued these systems somehow maintain the societal status quo by not profoundly redefining work and value (Wilson-Thomas, 2021). Overall, current sharing economy platforms and alternative networks are insufficient alone to address social and environmental unsustainability and injustice.

Solidarity, Not Charity

Considering these limitations, many authors from diverse disciplines call for more fundamental changes in the form and structure of socio-ecological relations (Schmid, 2021). In essence, they argue that the societal organization of production, redistribution, consumption, and decision, should be further transformed. Numerous potential transformative and emancipatory concepts have indeed been proposed concerning environmental issues and solidarity among which post-capitalism, post-growth or degrowth, commoning, subsistence, pluriverse, community or care-based economies, real utopias, and prefigurative politics (Gorz, 1978; Mies, 1999; Gibson-Graham, 2008; Wright, 2012; Demaria & Kothari, 2017; Kothari, Salleh, Escobar, Demaria, & Acosta, 2019; Hakim, Chatzidakis, Littler, Rottenberg, & Segal, 2020; Schmid, 2021; Healy, Borowiak, Pavlovskaya, & Safri, 2021; Monticelli, 2022; Laurin-Lamothe, Legault, & Tremblay-Pepin, 2023). These currents of thought, among various proposals, suggest the importance of finding ways of creating alternative networks of value where relationships between individuals and groups are not characterized by profit but solidarity and interdependence. It includes non-market-based approaches to supply through local production and free exchange of goods and services (ie. without any monetary compensations). Interestingly, various utopian imaginaries of universal solidarity have also been sketched by various authors: a community-owned "general catalog" (Saros, 2014) of free products and services, an infrastructure supporting a decentralized non-monetary economy in a post-market society (Fuchs, 2020), a "digital feedback infrastructure" implementing solidarity-based processes to match problem-finders and problem-solvers outside of the commercial realm (Morozov, 2019), a working prototype of a "civic platform" to combine both efficiency and solidarity (Muldoon, 2022a), a digital tool for community sharing and alternative neighborhood plans (p.m., 2009), ... While one could argue some of these ideas sound idealistic and lack pragmatism, diverse solidarity practices have actually spanned the ages (Kropotkin, 1902; Mauss, 1954; Sahlins, 1974; Cheal, 1988; Graeber, 2012; Vaughan, 2021). Although cooperation practices among strangers have been hypothesized to have declined over the last decades (attributed to a global decrease in social bonds), there are reasons to remain optimistic (Yuan et al., 2022; Zhou & Dong, 2023), and utopian imaginings somehow underlie thinkings of several participants of sharing platforms (Fitzmaurice et al., 2018; Schor, 2021). Moreover, recent tragic events (such as a flood, war, pandemic, storm, economic crisis or recession, ...) have also reminded us, on the one hand, that many people are vulnerable and require unconditional help. On the other hand, the impulses of solidarity can be numerous but efficient organization of solidarity actions is essential (Travlou, 2021; Mao, Fernandes-Jesus, Ntontis, & Drury, 2021). Research studies actually reveal a series of complementary solidarity concepts, exchange structures, and practices (Nowak & Sigmund, 2005; Bolton, Katok, & Ockenfels, 2005; Trivers, 2006; Moody, 2008; Herne, Lappalainen, & Kestilä-Kekkonen, 2013; Yoeli, Hoffman, Rand, & Nowak, 2013; Apeldoorn & Schram, 2016; Curry et al., 2018; Okada, 2020; Yuan et al. 2022; Zhou & Dong, 2023) named as gift economy, mutual aid, non-monetary sharing, network-generalized exchange, self-help, indirect reciprocity, third party or reciprocal altruism, or random acts of kindness. Mutual aid ("*solidarity, not charity*" (Spade, 2020)) and gifting are ancient practices in the history of humanity which have persisted to varying degrees through the ages (Benveniste, 1969). When gifting, one does not negotiate an immediate return. Gifting or generalized reciprocity

is the exchange of goods and services without keeping track of their exact value, with low obligation to reciprocate (with an eventual, implicit, expectation that their value will somehow balance out over time) or no obligation to reciprocate whatsoever. While in bartering or in direct reciprocity, parties directly exchange resources with each other (two actors A and B give benefits to each other in a relation of direct reciprocity: A gives to B, and B gives to A), indirect generalized exchange involves more than two parties: One actor A gives benefits to another B and eventually receives benefits from a third party (C or D or ...) (Molm, Collett, & Schaefer, 2007). Such generalized indirect exchanges are used for community cohesion through structuring social reciprocity, and they leverage community assets. Mutual aid has been a longstanding practice among communities who experience short-term and long-term crisis, and it is considered as a humanizing approach to care and a compassionate act based on shared humanity (Littman et al., 2022), based on the assumption we all have both needs and something to offer (one's role can shift from giver to receiver, or vice versa).

Nowadays, these longstanding conceptions of solidarity are continued or reinvented and materialized in different forms and places, including face-to-face interpersonal free exchanges (Lampinen, 2021); groups to support vulnerable individuals and offering free assistance (mutual aid (Spade, 2020), "*caremongering*" (Seow et al., 2021; Bishop et al., 2022)); stooping or curb alerts (the action of taking something off the stoop, or curb, that was left there for others to take, potentially with no in-person contact); gleaning (the humanitarian act (Badio, 2009) of letting people collect leftover crops from fields after they have been mechanically harvested (Marshman & Scott, 2019)); food growing in public spaces for public consumption (Farrier, Dooris, & Morley, 2019); give boxes and free shops (freely accessible places where everyone, without any access criteria, can come to deposit and acquire items), "*donnerie*" or "*gratiferia*" (free markets taking place on a specific date), grassroots food sharing networks to reduce food insecurity and food waste through the transformation of surplus food from a commodity to a gift (Berns & Rossitto, 2019); community and solidarity fridges (somehow similar to "give boxes", but for food (Zain, 2023; Chies, 2017)); repair cafés (free events where people can bring in broken or damaged items to be repaired by volunteers, (Moalem & Mosgaard, 2021; Schägg, Becker, & Pradhan, 2022)); or even free little art galleries (Jones, Nousir, Everrett, & Nabil, 2023b). In this paper, our aim is to better understand the social environment and how Shareish, a technological platform under development, can facilitate and nurture these diverse solidarity practices.

Main Limitations of Current Software Technologies to Foster Solidarity

Design decisions made by technological platforms (including social networks and digital maps) can have immense impacts on how we experience our neighborhood and our world. They shape our understanding of it and of our place within it (Graham, 2022). While mainstream technological platforms mainly highlight for-profit entities and ease commercial transactions, digital tools can alternatively support logics of reciprocity (Schor & Vallas, 2021) and solidarity can be triggered from online spaces to offline communities (Zhou & Dong, 2023). Recently, some features of the popular social media platforms (e.g. Facebook groups or Google Sheets) have actually been extensively used for mutual aid and care in

acute crisis situations (Knearem, Jeongwon, Chun-Hua & Carroll, 2021; Seow et al., 2021; Travlou, 2021; Wilson, Roskill, & Mahr 2022; Zhou & Dong, 2023). While their use was instrumental by contributing to fill gaps in essential supplies and services left unfilled by the State, these platforms have several drawbacks. First, their design often leads to time-consuming and laborious work (e.g. scrolling through a group's Facebook timeline to find aid requester's or providers' posts, Knearem et al., 2021). Moreover, aforementioned commercial platforms (and others, such as Nextdoor) create individual and collective tensions including political conflictuality and practical powerlessness (Rossitto et al., 2021; Masden et al., 2014; Payne, 2017). Political tensions include the fact the platforms that underlie so much of our daily lives and social interactions are controlled by a small group of owners who remain largely unaccountable for their decisions (Lynch, 2019; Forestal, 2022; Muldoon, 2022b). Practical powerlessness can result from the fact that their source code is proprietary (not accessible), so these platforms can not be finely community-controlled but only managed by an external entity. In practice, proprietary platforms cannot be easily scrutinized or extended by their actual users (or by HCI researchers) to fit their specific needs. For example, it is not well-known how posts in a Facebook group's feed are ordered, and neither software developers nor aid providers can change this ordering according to practical considerations. Pragmatic design tensions (Rossitto et al., 2021) also encompass the absence of guarantee an existing, useful, feature will remain available or affordable. In practice, it is not uncommon that a single entity managing a dedicated platform decides to discontinue it, or to reorient its objectives or features for commercial reasons. For example, the *Jaspr Trades* for "cash-free swap community in Berlin" (https://www.instagram.com/jasprtrades/) suddenly ended its activity, the renting platform *Usitoo* in Belgium did not find a sustainable business model and was discontinued (https://end.usitoo.be/), the *Kassi* online forum "with the aim of linking those who can give something to those who are in need" (Lampinen, 2021) became as a start-up company the "*Sharetribe* online marketplace to sell, buy, and lend stuff", the *Geev* platform (https://www.geev.com/) started to implement commercial ads then premium features that restrict which free items non-subscribed users can see, a decision followed by several comments of unsatisfied users feeling pushed out of the application by increasingly aggressive monetization practices. In contrast to such closed-source, proprietary, software licensing carried out by most sharing platform companies, open-source distribution means the whole recipe of a software platform (its source code) will remain available and readable by third-parties, so the suite of operations behind each software feature can be scrutinized. Moreover, a free open source license permits third-parties to modify, use, and redistribute the software for any purpose, based on the notion of "common humanity" (through the mutual dissemination of knowledge and the acknowledgment of the abilities of each individual to act and to do) (Boltanski & Thévenot, 2006; Depoorter, 2020). Therefore, it potentially allows its reuse by various communities (including less-resourced grassroots groups) and the seamless launch of bottom up, self-organized, initiatives rooted in daily lives. Open-source technologies for sharing could also be good candidates to contribute to the emergence of communities (Abou Amsha, Gronvall, & Saad-Sulonen, 2023), they could favor processes of proliferation (Larsen-Ledet et al., 2022) and help to resist to the influence of the growth discourse of corporations, towards local caring arrangements where citizens are empowered, as exemplified by the collective experiences of technological sovereignty, grassroots digital urbanism, or civic tech grassroots (March, 2018; Lynch, 2019; Vadiati, 2022; Knutas et al.,

2022). Overall, they are expected to increase human autonomy by enabling the creation of tools for conviviality (Illich, 1973) and autonomous spaces adapted to local conditions that are not subjected to a centralized control, hence reclaiming a greater human dignity (Keyes, Hoy, & Drouhard, 2019; Swann, 2022).

Moreover, existing platforms are also not (or only weakly) exploiting geolocalizations whereas community maps can better raise consciousness and produce forms of empowerment (Parker, 2006; Buoli, 2014). In practice, using current platforms, it is not easy to discover local free ressources and to be aware of solidarity actions in one's immediate surroundings. While access to earlier geographic information systems was a concern (Sieber, 2006; Craig, Harris, & Weiner, 2002), modern online maps are now often considered as an ideal interactive, mobile, and collaborative interface between a human, groups of people and the dynamically evolving environment (Kraak & Fabrikant, 2017). Online maps enable users to better engage with reality (Hiltz et al., 2020; Auferbauer & Tellioğlu, 2017) for emergency/disaster management where it is suggested data should be displayed by geographic location on maps in relation to the user's current position, rather than as item lists (e.g. posts on a Facebook Group's feed). Similarly for gleaning, (Badio, 2009) suggests mapping services are vital to long-term success as digital maps can help to coordinate multi-actor initiatives and to share knowledge. Geographical proximity is also viewed as a critical factor for those who participate in sharing (Fors & Ringenson, 2023), and maps can be used in various ways to enable civic participation in urban environments (Yu & Cai, 2009; Tzanidou & Vlachokyriakos, 2022). Several human geographers and philosophers have also pointed out the potentials of maps (seen as platforms for locally situated knowledge) e.g with concepts of maputopias (Gutierrez, 2018), caretographies (Hind, 2017), and transformative or radical cartography (Cohen & Duggan, 2021). These works suggest ordinary citizens can collaboratively generate maps to produce an alternative, dynamic, useful, community-owned representation of a territory in order to open avenues of social transformations previously held inaccessible or invisible (Denil, 2011), or to chart new desires and hopes for a better future into the landscape (Firth, 2014). The map of the visible represents the realm of possibilities and prepares us for action (Zwer & Rekacewicz, 2021). Maps are considered as tools that can be made and used with the aim of transforming territories and landscapes according to social projects, they contribute to shaping territories and not only represent them passively (Besse, 2023), they have the potentials to construct new propositions about how the world is represented and organized (Graham, 2022). After all, technological tools and digital maps are massively used by citizens e.g. to localize and use bikes or electric scooters in large cities, so there is no technical reason that this cannot be the case to easily access other free resources while promoting solidarity and reuse.

This Work: Understanding and Facilitating Diverse solidarity Practices Through Online Community Mapping and Open-Source Practice

Given all these limitations on the one hand, but also all the unexplored potentials on the other hand, the work we present in this article is in line with various HCI works that have suggested that novel sociotechnical tools could be created to experiment the move from a market logic to the co-creation of human economies (Vlachokyriakos et al., 2017), in other

words toward advancing sustainable, just, and humane futures (Sharma, Kumar, & Nardi, 2023).

The following sections expose the results from new qualitative investigations of local solidarity practices and present the extended design of Shareish ("Share and Cherish") (Guilliams, 2023), a modern, map-based, web platform dedicated to people driven by mutual trust, comradeship, and generosity and refusing to measure and remember who had given what to whom, with the long-term goal to increase random acts of kindness and more broadly solidarity practices at the street corner or beyond. This platform is centered around an interactive, user-editable, digital map, advanced search functions, and communication modules that can be easily deployed to foster diverse solidarity practices. While (Guilliams, 2023) was mostly focusing on generalized (face-to-face) exchange of geolocated goods and services, here we first took efforts to better understand the social environment where Shareish could grow with the help of local actors of solidarity communities to learn from their creativity and experiences. Software-wise, our extended version offers functionalities that are in line with a greater diversity of locally situated solidarity practices, and new user interfaces. As the previous software version, the extended version of the whole system is distributed under an open-source permissive license as a gift to the society, and to foster further developments by communities, CSCW, and Solidarity HCI developers. From a computer science perspective, the Shareish platform is at the intersection of human-centered informatics and solidarity HCI, modern web/software development, digital mapping, spatial database design, and container technologies. In addition, Shareish exploits recent research in artificial intelligence to ease user experience. Limitations of this work and design opportunities will be discussed before we conclude.

DESIGN METHODOLOGY

Establishing Platform Requirements Through Literature Review, Online Ethnographic Observations, and Qualitative Research

Designing an online platform for ICT-mediated solidarity practices necessitated learning about the diversity of practices (see e.g., Figure 1) as well as the needs and problems of the intended users. To this end, we extended the design methodology described in (Guilliams, 2023) and relied on additional data sources and initiatives. We expose below our design methodology into three main complementary approaches.

First, we extended our literature review of research papers related to solidarity practices in a more broader sense. We carried out a thorough analysis of papers describing mutual aid groups created during the COVID-19 pandemic with tens of thousands of requests/aids (Knearem et al., 2021; Seow et al. 2021; Travlou 2021; Wilson et al., 2022; Zhou & Dong, 2023); papers that have retrospectively analyzed thousands of transactions in Timebanks or online forums for local communities (Collom, 2012; Kyungsik, Shih, Bellotti, & Carroll, 2015; Glückler & Hoffmann, 2021; López & Farzan, 2015); papers describing gleaning (Badio, 2009; Marschman & Scott, 2019) and solidarity fridges initiatives (Chies, 2017; Zain, 2023; Kiden, Strohmayer, & Yee, 2023); previous C&T, CSCW, and HCI research works that relates to the design of community/sharing platforms in a human-centered way

(Suhonen, Lampinen, Cheshire, & Antin, 2010; Feng, Li, & Li, 2013; Bellotti et al., 2013; Bellotti et al., 2015; Yu & Cai, 2009; Luckner, Fitzpatrick, Werner, & Subasi, 2015; Light & Miskelly, 2015; Lampinen et al., 2017; Dillahunt et al., 2017; Lampinen, 2021; Fedosov, Albano, & Langheinrich, 2018; Hiltz et al., 2020; Fedosov, Cheok, & Huang, 2021; Knearem et al., 2021; Fedosov, Lampinen, Odom, & Huang, 2021; Ntouros, Kouki, & Vlachokyriakos, 2021; Jones, Nousir, Everrett, & Nabil, 2023a; Fors & Ringenson, 2023; Fedosov, Zavolokina, Krumhard, & Huang, 2023) and whose authors have derived design guidelines and opportunities (through case studies, interviews, and participatory design workshops).

Second, we performed additional online ethnographic observations involving several groups and platforms related to gifting and solidarity. These punctual observations include four french speaking Belgian Facebook groups centered about gifting between users (including a city-wide "gifting" group with more than 40K users from which we sampled 200 posts over a period of three months in 2022); two Facebook groups about gleaning (where farmers or individuals announced the location of fields where gleaning was possible, September-October 2023, Wallonia, Belgium); data from a specific, closed-source, web platform (https://aide-inondations.be/) created following a major flood (100 random posts randomly sampled over a period of one month following the tragic event in summer 2021, Liège, Belgium); Instagram profiles for stooping (we found more than 100 worldwide profiles, with groups that can range from a few dozen users to several hundred thousands, autumn 2023); Instagram profiles and Facebook pages for community fridges (in US cities and in Liège, Belgium, autumn 2023); and user comments about the *Geev* App for donating items between individuals (https://play.google.com/store/apps/details?id=fr.geev.application). We also observed *Vinted* (https://vinted.com/, a commercial platform for secondhand items), *Facebook Marketplace* (https://www.facebook.com/marketplace), *Mytroc* https://mytroc.fr (a LETS platform using a virtual currency), and on https://www.freecycle.org/ (a bulletin board for donations and requests). Furthermore, we analyzed *SolidarityCityMap* (https://solidary.city/) and *Priceless* (https://priceless.zottelig.ch/), two maps that show places where people can participate in city life without papers or money; as well as two applications to update *OpenStreetMap* database content (https://www.openstreetmap.org/, the free editable map of the world): *StreetComplete* (https://streetcomplete.app/) and *MapComplete* (https://mapcomplete.osm.be/).

Third, to better understand how people demonstrate solidarity and to explore the environment where Shareish intends to insert itself, we conducted a qualitative study on mutual aid and giving practices, described in the following subsection.

Figure 1. Illustration of some solidarity practices in Belgium. From left to right: dishes on a window sill in Liège (stooping), public bookcase in Champion-la-Famenne, storefront of a free clothes shop in Ghent, solidarity fridge in a street in Liège, table with toys for children in a free market event in Ans, a give box for small objects in Saint-Nicolas. Images by Researcher.

Understanding Diverse Needs, Interests, and Values from Local Actors

For this research, we met people from different initiatives in Belgium, selected according to their diversity. In the region of La Louvière, a local Facebook Group allows members to post offers or needs for peer-to-peer gifting while also hosting a physical shop offering clothes and other small items for free. In the region of Ghent, we visited a free clothing shop hosted in a long-term squat with a storefront in a commercial street. In the region of Liège, we participated in a free market ("donnerie") organized in a local cultural center. We also conducted on-site observations of events dedicated to giving; we occasionally conducted qualitative interviews with organizers of these events and volunteers. All names that follow have been pseudo anonymised.

Our observations and interviews guides were oriented towards the understandings of participants. Our interests and questions were not bounded to their gifting practices and behaviors but also explored related values, purposes or beliefs. We also questioned the current uses of digital technologies (such as social media) and the dispositions to adopt alternate digital tools (such as Shareish).

A trace of each observation was kept by writing field notes; each interview was audio recorded and transcribed. The resulting field notes and interview transcripts were shared among co-authors thanks to Cassandre, a collaborative platform dedicated to qualitative team research (Lejeune, 2011). As soon as it was available, each piece of empirical material was coded, by one researcher at once, either by the one who collected it or by a different team member. At least three team members discussed each code candidates in order to improve it. Grounded Theory Method (Charmaz, 2006; Lejeune, 2019) furnished the principles governing these enhancements. Codes eliciting the participants subjective experience were preferred to thematic coding. Broad or all-encompassing codes were thus avoided in favor of codes eliciting the specificity of each context or situation. Of course, our discussions were also guided by the practical purposes of the study (design).

Discussions about codes eventually raised questions to be addressed during the next field contact. In an iterative design, observation/interview guides were thus different for each contact (which ensures fieldwork productivity).

Sense of Community

We found that maintaining a free shop requires a substantial investment of labor and resources. This work is performed by volunteers who dedicate their time to greet visitors and maintain the store's cleanliness and organization (Ghent, 02/2024). Similarly, online communities require considerable work to moderate their space and help users struggling to understand how the group functions (La Louvière, 01/2024).

While a significant number of group users or free shop visitors are occasional or even one-time participants, regular involvement in a giveaway initiative can foster a deep sense of community and belonging among its long-standing members (La Louvière, 01/2024). These communities weave a complex network where the skills and resources of every volunteer and elements of their environments make each initiative unique. *"The shape of the shop has been completely determined by the people working in it. It's [made with] a unique group of people and the context of the neighborhood and everything."* (Hugo, Ghent, 14/02/2024). In Ghent, we learned about the history of the neighborhood where the squat is located and its impact on the shop's identity. The street was previously an important commercial street of the area and it is acting as a facilitator that made the shop more inviting for curious older residents. Similarly, online groups can become a place to advertise local events or even for some participants to simply write greetings to others (La Louvière, 01/2024; Online observations 12/2023).

Rules

This uniqueness extends to the rules, formal and informal, that each store creates. Free stores (Ghent, 02/2024), giveaway events (Ans, 11/2023), and Facebook groups (Online observations 12/2023) all require their users to follow certain explicit or implicit rules to be able to function. These rules vary greatly with regards to volunteers maintaining it, their participants, and even acting entities such as their location or their infrastructure. These rules and know-how need to be learned by users so that the group or store can function and a sudden influx of new users is hard to manage. *"Like I think sort of comparing it to being [in a] city center. If [we were,] we would be engulfed by people that have no connection to any kind of community or social behavior every week it would be very difficult."*(Willem, Ghent, 14/02/2024).

These rules can be minimal or regulate conditions for the gift or the future usage of items. When organizers of a store decide that items going through their free shop must not be sold, they track users online and in person to make sure they intend to use the gift they intend to take. When there is a doubt on the intent of the receiver, volunteer organizers can search online for the item being resold. If caught, the contravener would then be banned from the community (La Louvière, 01/2024). In physical free stores, organizers can also investigate the users interested in taking an item seen as valuable with questions to test their intents (La Louvière, 01/2024). Other initiatives consider that the destination of the gift is out of their scope. For Hugo (Ghent, 02/2024), gift, movement, and flow prevail over the intentions of the recipients and if someone finds a way to earn money from their clothes they probably need it anyway. Some forms of giveaway can also mandate a donation to take part. In a giveaway event in Ans (11/2013), organizers chose to ask each visitor to bring at least an item to be given in exchange for a ticket used to leave the event with up to ten gifts. The gift

brought was not expected to be proportional to the item taken. When asked, the organizers explained that this rule was put in place to avoid the feeling of charity for its visitors.

Roles and Meanings

Such practices might seem at odds with some of the driving principles behind the gift economy but reflect that gifts can take on multiple meanings for each participant involved, or even multiple meanings at the same time. The meanings of solidarity practice can be deeply rooted in the anarchist currents of thought (e.g. Kropotkin, 1902) but can also be seen as an ecological act of fighting against overconsumption or a simple act of solidarity for those who need it and might be in dire circumstances. Teaching these meanings to visitors or users helps them go past initial resistances. Some of these resistances might be that the gifts should be left to only the most needy or that there would be an inherent dirtiness to used items (La Louvière, 01/2024). We saw that a free shop can achieve this aim through accessibility, regularity, and a welcoming atmosphere (Ghent, 02/2024).

For a giveaway platform to last, the collaboration of both event organizers and individual sharers and receivers of gifts is needed. Those two profiles are not distinct in practice and overlap greatly but can be used to highlight some of the different interests we have identified so far. Regular users of the gift economy play different and often multiple roles in free exchange. While sorting received donations in their free shop, actors discuss their last donation while boasting that everything they wear came from the free shop (La Louvière, 01/2024). On the other hand, when looking at the reported size of some Facebook groups and the history of their users, it appears that offering a gift or making a single request and then stopping their participation in those groups is a regular occurrence (online observation, 12/2023).

For an organizer of an event or free shop, using a new platform to advertise their initiative is not particularly labor-intensive but advertising an individual offer on a new platform represents a greater amount of work. To create a receivable gift offer on a Facebook group, a user needs to understand and provide the minimum information required. If some information is missing or generates multiple comments to request the missing information, a post might be received with hostility or won't be approved by the moderator. These expected pieces of information can be factual and practical like the nature and location of the gift or the need but it can also include the expectation of a "hello" or a "please" (La Louvière, 01/2024). Users need to learn to take pictures showing their offering in its best light and include all necessary information in the post to avoid misunderstandings. This process takes a considerable amount of time and can be an obstacle to the participation of some less technologically inclined users. A group can also facilitate this process by working as a free store and receiving gifts for which donors do not want to take the time to post them online (La Louvière, 01/2024). This also highlights the complexities of building an efficient post-creation process as the complexity is highly dependent on the user. In online communities, when some less technologically inclined users with good intent struggle to craft a post following the expected standard of an online community, some more experienced users might contact them and help them (La Louvière, 01/2024).

To work day-to-day, each free shop needs to maintain a careful balance, gifts come in by the bag and items come out in much smaller numbers. This balance is created and maintained by the constant filtering and sorting of organizers. In the case of gifted clothing, the supply

can often appear never ending for both projects and the act of filtering what is worth keeping is an important operation of the day-to-day gift economy. To be a good sorter, volunteers need to be very selective to make sure their limited storage is not filled with objects no one wants. Volunteers need to balance the need for a stock that will be desirable and prioritize less often received items such as male clothing or scarcer sizing (Ghent, 02/2024).

Matters of Fairness

When several users are interested in the same gift offered through an online platform, users are in effect in competition for who will receive the gift. In such a situation, it is easy to feel disadvantaged against those who are more regularly connected on the platform. To address this difficulty, some groups mandate a three-day waiting period on any offer before the giver can choose the receiver of their choice (La Louvière, 01/2024). These efforts reveal how organizers aim to provide an equal opportunity for each to use the platform but some users try to circumvent them by sending private messages directly to the giver and offering money for the item (La Louvière, 01/2024). When no feeling of competition is felt, users and organizers rely on the large supply of gifts to fulfill the needs of visitors (Ghent, 02/2024). Even when it is not explicitly forbidden, introducing money in a free exchange can be seen as unfair or hurtful to actors. While a donation box might exist for convenience, it is much preferred to contribute your time, gifts, or resources directly (Ghent, 02/2024).

Matters of Mobility

For online communities of givers, an important concern lies in the mobility of the gift. When users do not own or do not wish to operate a car, any movement to and from the gift location can be costly in time and effort. The availability of a car or access to public transportation is an issue for givers and receivers, as for organizers. Some online communities have begun to organize storage and a network of relays throughout their region (La Louvière, 01/2024). Here, the system relies on the gift being dropped in the free shop associated with the group and then stored in a dedicated box labeled with its intended destination. Regular users were willing to act as relays and to pick up and store these gifts at their homes for their receiver to schedule a pickup. Even though it is uncommon or banned in the community rules, traveling to deliver a gift can also be accepted as long as the receiver could not reasonably be expected to due, for example, to their age, health, or living condition (La Louvière, 01/2024). When gifters or receivers do not show up to a scheduled appointment or if the involvement of one of them is perceived as insufficient, a user can be sanctioned by the community through a message, a bad reputation, or even a ban from the platform (La Louvière, 01/2024).

SHAREISH PLATFORM

The first version of the Shareish platform and its iterative design, development, and development cycle were described in (Guilliams, 2023). Since then, design requirements were refined following the extended design methodology described in the previous Section. Here, we first summarize the general, updated, design requirements. These requirements are then translated into software functionalities, and then into their technical implementation (available in the form of an open-source software). Limits and additional design opportunities are later discussed.

Summary of Design Requirements

Our extended design methodology allowed us to derive the following requirements:

1. *Usability and ease of access*: The platform should be accessible on both personal computers and mobile phones (Fedosov et al., 2018), take into account the community diversity (incl. multilingualism); provide various hints and helping functions. Platform access should comply with community perception of fairness.
2. *Locally situated*: the platform should provide a strong connection to geographic location to foster a sense of community within a hyperlocal environment (Suhonen, Lampinen, Cheshire, & Antin, 2010) and allow participants to discover and mobilize resources from their immediate surroundings (López & Farzan, 2015; Fors & Ringenson, 2023), while taking into account people's ever-changing location (Bellotti et al., 2013) and residential instability (López, Farzan, & Lin, 2017), so without rigid assignment of users to a neighborhood (Masden et al., 2014; Payne, 2017). An online interactive map is considered the most useful tool to find shared objects and public resources within or beyond users' immediate neighborhood (Fedosov et al., 2021), and it is strongly advised for managing tasks in emergency situations (Auferbauer & Tellioğlu, 2017; Hiltz et al., 2020). The digital map should allow individuals to encode specific locations (with geocoded address names or precise GPS coordinates) as exchanges processes and places can be in various forms within a community, e.g. a street address for interpersonal face-to-face exchange at home or at another safe place; a field for gleaning; or various physical intermediaries such as a free shop or a shared space in a building (Lampinen et al. 2017; Zhou & Dong, 2023); a curb, a public bookcase or a give box (for indirect exchange with no in-person contact).
3. *Solidarity through diverse practices*: The platform should allow individuals or groups to undertake various forms of solidarity actions (ranging from face-to-face to no in-person exchanges) in order to satisfy basic needs first (Bellotti et al., 2015) while also mitigating their potential feeling of indebtedness (Lampinen, 2021). The platform should make it just as easy to offer, lend (for free), ask for help, add free events, or add public free resources, so that individuals or entities can get involved spontaneously in different ways and switch between roles and create value together (Carroll & Bellotti, 2015). To allow wide participation across a community, it should provide open access to basic, freely available tangible goods, services, and events. According to previous studies (Knearem et al., 2021; Seow et al., 2021; Travlou, 2021; Mao et al., 2021; Wilson et al., 2022; Collom, 2012; Han et al., 2015; Glückler & Hoffmann, 2021; López & Farzan, 2015) and to our observations, users should be able to offer/seek a wide variety of time-sensitive items (goods services) e.g. (cooked or raw) food, clothes and blankets, pick-up of essential materials, drop off of groceries, transportation to medical appointments, HVAC equipments (air conditioners, dehumidifiers, heating systems), helping hands for a move or cleaning, assistance with administrative tasks; as well as announcing free activities.
4. *Fine-grained content information*: Providers (resp. receivers) should be able to precisely describe a great variety of goods and services they are providing (resp. seeking) rather than only through generic categories that are insufficient in the details they convey (Fedosov et al., 2021), including the possibility to associate multiple

images to describe items. Clear time limits must be definable to minimize efforts required to manage posted content (Lampinen et al., 2017).

5. *Efficient user content creation*: The platform should provide various auto-completion mechanisms to help users to easily add structured content (Knearem et al., 2021; Fedosov et al., 2021) in order to create active-enough streams of content (López et al., 2017). This might be facilitated by the reappropriation of emerging AI recognition technologies (Teli, Lewkowicz, Rossitto, & Bødker, 2021).
6. *Efficient content search and scalability*: The platform should provide different ways for searching and visualizing items based on their location and various filtering and ordering criteria exploiting their rich descriptions, rather than laborious scrolling through an infinite list of posts without any control on how items are presented (Knearem et al., 2021).
7. *Continuous perception of activity*: The platform should provide users information about site activity for building a sense of social presence (Suhonen et al., 2010) using mechanisms to display site usage, and configurable proximity notifications that indicate activity in the neighborhood (e.g. instantly when someone encounters an unexpected need (Bellotti et al., 2014) or posts a new offer; or only daily/weekly notifications) (Fedosov et al., 2021).
8. *Building user trust*: The platform should provide mechanisms to build interpersonal trust between users involved in face-to-face exchanges, e.g. to allow intuitive communications between users and progressive self-disclosure to accentuate common interests between users (e.g. using profile with/without name and possibly multiple pictures, with precise/approximate location, and through asynchronous or real-time private and public dialogue) (Feng et al., 2013; Fedosov et al., 2018; Pan, Feng, Wingate, & Li, 2020; Knearem et al., 2021; Lampinen, 2021; Fedosov et al., 2023).
9. *Transparent data processing and privacy*: The platform should provide ways to scrutinize how user's data are handled to improve trust (Scholz, 2016; Masden et al. 2014), and allow parametrization of notifications, unwanted message blocking, as well as allow users to disable or delete their account.
10. *IT Management*: The platform should ease day-to-day organization (Luckner et al., 2015) including modules for system administration (installation, maintenance, backup), content curation, and data extraction. The platform should be easy to replicate so it can be reused and adapted for different places and communities (Sieber 2006; Lampinen, Rossitto, & Gradin Franzén, 2019; Larsen-Ledet et al., 2022).

Main Functionalities

Shareish functionalities fulfill aforementioned design requirements. On a deployed Shareish server, users (individuals or entities) can indicate they want to either give (Donation), loan (Loan), or ask for (Request) items or services, as well as announce Events. In addition, they can add or edit public resources (such as public bookcases, give boxes, …) and associate donations/requests to them (so as to use them as physical intermediaries). Adding content can be done directly by adding a marker on the map, or through a form page. Users can also easily discover what other users have to offer or what they request [Reqt 3], using various interactive mechanisms (a map [Reqt 2] and a browsable list with advanced filters [Reqt 6],

configurable notifications of new content [Reqt 7], and textual private conversations or public comments [Reqt 8]). Shareish user interfaces have been designed to make it easy to adapt to other languages (internationalization) [Reqt 1], and it is currently available in English and French.

Users

A Shareish user can be a provider or a receiver [Reqt 3] and create various types of content at various places [Reqt 2]. In our data model, a *user* is typically an individual acting on his behalf (but it might be a representative of an organization) to which a unique e-mail address has to be associated to register on the platform. In addition, the user can provide an additional textual description and links to other social networks, as well as several profile pictures [Reqt 8]. In their profile, users can also indicate a reference address [Reqt 2] that can be used to get *notifications* (instantly, daily, weekly, monthly, or never) by e-mail when new content (items, events, public resources) is published [Reqt 7] in a configurable neighborhood (based on the *distance* as the crow flies [Reqt 2]). Users can enable or disable the recording of the items they see on the platform (to be able, or not, to filter them), and they can temporarily disable or definitely delete their account [Reqt 9]. If individuals do not want to register on the platform, they have the possibility to view a map with public resources only and limited functionalities (other users' personal items are not displayed and direct interaction with them is not possible).

Items and Free Public Resources

A user can add or search content on the platform. Each piece of user-contributed, semi-permanent, content is called an *item* and it can be either a good (e.g. a mower to lent or to give), a service (e.g. to mow your lawn), or an event (e.g. a free Repair café, an assembly meeting) [Reqt 3]. More precisely, when a user adds an item, they have to choose an *item title*, an *item type* (Donation, Loan, Request, Event), and up to three *item categories* among a list of predefined categories that cover a large number of goods and services (Food and Supplies; Pets and Animals; Arts, Culture, and Entertainments; Collectibles and Decoratives; Helping hand and Manual Labor; Administrative tasks; Do-it-Yourself; Beauty and Well-being; Health; Energy and Heating; Childhood; Clothes and Shoes; IT and Multimedia Hardware; Informatics Software; Gardening and Nature; Living spaces and Housing; Tools and Equipments and Ustensils; Holidays, Week-end, Leisures; Books and Magazines; CDs, DVDs, Blu-rays, Discs; Sports; Transportation, Delivery, Pick-up, Moving; Vehicles and Means of transport; Other) [Reqt 3]. In addition to a *textual description*, *images* can be associated to an item so other users have access to precise information about it [Reqt 4]. Importantly, a physical *address* can be associated to an item [Reqt 2], hence each item can be displayed on an interactive map, so that other users can discover easily available items in their neighborhood (and be notified with approximate distance information [Reqt 7]). The address can be either very precise (including street name and number, or GPS coordinates) or rather vague (city name), the choice being left to the user to reveal or not their item precise location [Reqt 8,9]. In addition to user content, users can add permanent public resources (public bookcases, give boxes, free shops, solidarity fridges, drinking water sources, edible foraging spots).

Auto-completion mechanisms and content management

Encoding item metadata might take a while and can be a barrier to the creation of new content. We provide several mechanisms to ease this process [Reqt 5]. First, if an item is created directly from the map, its precise address is pre-filled in the item form. Alternatively, the item address can be directly copied from current user location (provided they accept geolocalization through their browser settings) or from their reference address encoded in their user profile. If an item is associated with a public resource (e.g. a request related to a community fridge), item categories are pre-filled and descriptions are suggested (e.g. “request to clean the fridge”). Moreover, once a user associates one or multiple images to their item, an auto-tagging workflow is executed. The first step uses a deep learning classification model that takes an item image as input and that outputs a term from a list of 1000 object classes. The five most likely terms can then be used to fill the title field of the item (e.g. tomatoes) and the chosen term is mapped automatically to one of the twenty Shareish categories (e.g. Food and Supplies) to auto-complete the category field. In addition, when the item image contains text, an OCR engine is used to recognize text and inserts the detected text into the description field of the item. This can be used e.g. to ease the encoding of books (as evaluated in (Guilliams, 2023)) or flyers announcing events. All these pre-filled fields can be manually edited. To further reduce manual encoding, a user can mark an item as recurrent to ease its resubmission at a later stage. For example, if a user has an apple tree and they have too much apples at each harvest, they can encode an item called "apples" and make it recurrent so that the next time they will go to this recurrent item and repost the "apples" without the need to encode details again (similarly for recurrent requests e.g. weekly grocery delivery; or recurrent events where only the start and end dates would need to be changed). The owner of an item can also set its visibility level: public (visible for all registered users), unlisted (only visible with the direct link to the item), or draft (only visible by the item owner). An item can also be deleted from the platform by its creator. To minimize efforts required to manage posted content [Reqt 4], a start date and an end date can also be specified, so that the item will automatically disappear after the end date. This can be used in multiple ways, e.g. to automatically delete past events or perishable items, or to request a service within a specific timeframe.

Interactive Map and List

By default, the interactive map and the listing-page show all items and are two complementary ways to access a Shareish server content. The interactive map allows users to explore data based on geographical locations using zooming, navigation, and address search. The item list enables sorting items according to various criteria (by publication date, start date, end date, distance, public comment counts, view counts) [Reqt 6], and displays item distance information as well as viewing counts [Reqt 7]. To further ease discovery [Reqt 6], filters can be applied both on the map and on the item list page, and these settings are saved. These filters can be a combination of item type, item category, item availability, item location, item publication date, item view status, or based on textual search (the search is performed over all item titles and textual descriptions). Such a combination of multiple criteria allows to search e.g. "unseen requests for help related to clothing in a neighborhood of 2km published during the last 2 days, sorted by distance". In addition to user contributed items stored in Shareish database, it is also possible to display and add on the map free

amenities (public resources) including public bookcases, give boxes, free shops, drinking water sources, food banks, soup kitchens, defibrillators (all interfacing with OpenStreetMap database), and falling fruit spots (interfacing with Falling Fruit, a crowdsourced database of fruit trees and edible plants on public land). Users can activate or deactivate their display on the map. By combining filters and check-boxes on the map, users can directly access relevant data in their current vicinity [Reqt 2,6].

Conversations and Public Comments

A Shareish server enables online communication between users through public comments or private interactive conversations. Public comments can be associated with items on each item details page. For each item, it is possible to start an online textual conversation between the provider and the receiver in the "Conversations" module. It allows to get further details about the item, to get to know each other [Reqt 8], and ultimately to arrange an appointment in the case of face-to-face interpersonal exchange (e.g. to reveal the exact address and choose the time at which the exchange could take place). The first message of a conversation is automatically suggested based on the item type and can be further edited before being sent. Both the UI and an e-mail mechanism are used to notify users when they receive messages to foster activity, similarly to notifications for items and events. Conversations can be searched (using item title). To prevent threats to user's personal privacy [Reqt 9], a user can lock (unlock) a conversation to stop receiving unwanted messages.

Technical Implementation

Delivering these functionalities in a way that is effective for users requires modern and robust architecture and user interfaces compatible with a variety of user devices [Reqt 1]. The architecture of the platform is depicted by Figure 2. It follows a representational state transfer (REST) Client-Server architecture style that structures database resources and that standardizes communication interfaces to improve interoperability. Our underlying data model, an extended version of (Guilliams, 2023), is implemented using a spatial, relational database where we store data related to the aforementioned concepts of users, items, and conversations (see Figure 3). Concretely, our implementation is divided into two main parts: the front-end (client-side, illustrated by Figure 4-10) and the back-end (server-side), described below. For each part we wrote source code following common practices in software development (incl. component-based and object-oriented programming practices) and we combined modern, popular programming languages and existing open-source libraries to facilitate its maintenance and reappropriation by other software developers.

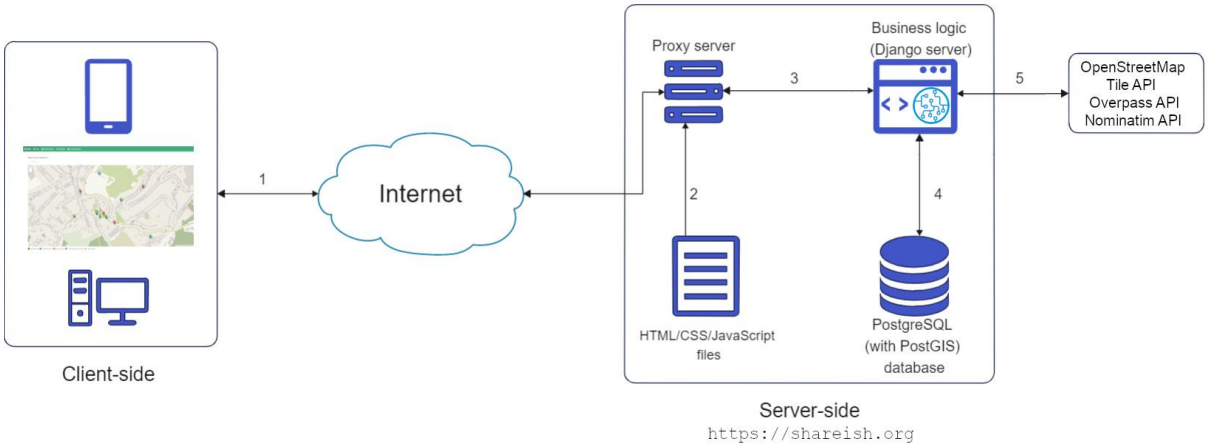

Figure 2. Overview of Shareish web architecture (Source: (Guilliams, 2023)). A Shareish server instance (here: https://shareish.org) can be accessed through various clients (web browser or mobile) which send requests to the server composed of three containers (proxy, web framework, database). The proxy server receives requests and redirects requests to the web container (Django framework) which handles the request and sends either SQL requests to the database container (PostGIS) to fill web pages with data user or item data, or requests to external APIs to load cartographic data, namely OpenStreetMap Tile API (to display map tiles), Nominatim API (to convert physical addresses to geographical coordinates), Overpass or Falling Fruit API (to display external data sources). The AI auto-tagging module is included in the web container.

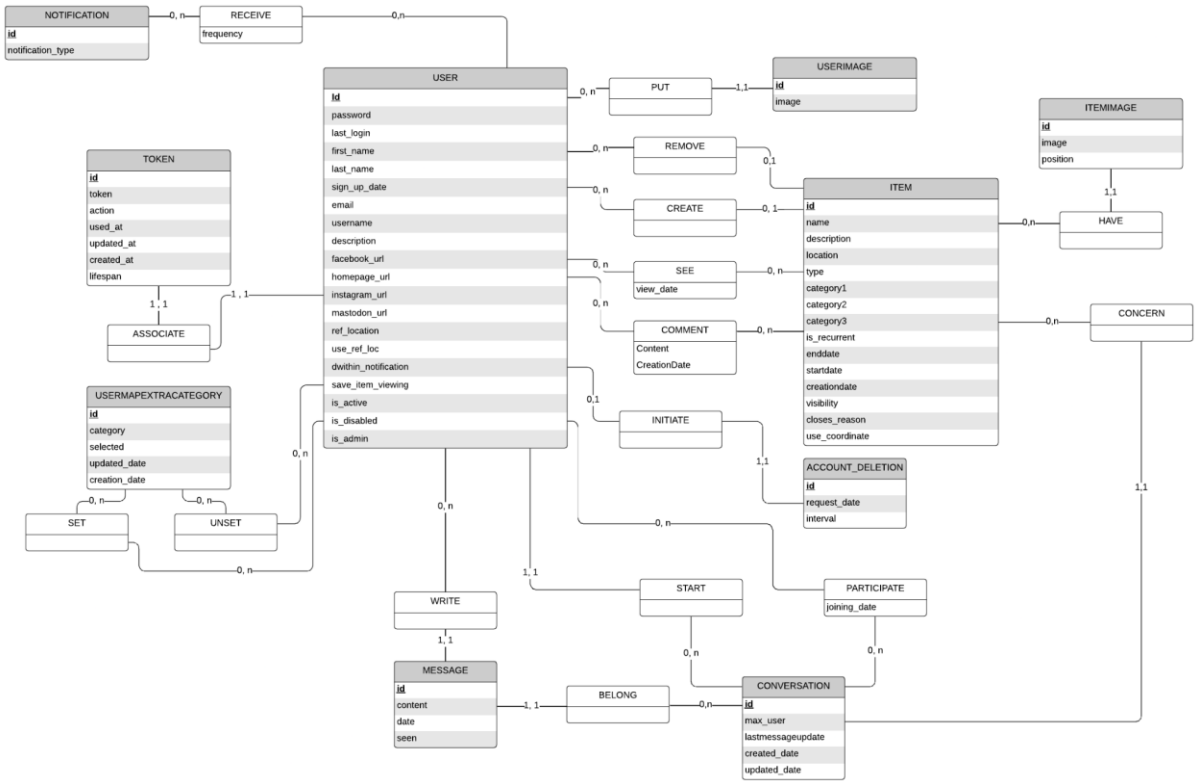

Figure 3. Overview of the Shareish conceptual data model with main entities: User, Item, Conversation (all details are not shown for readability).

Front-end

The front-end regroups all the code necessary for the web user interface and mainly revolves around VueJS (https://vuejs.org/), a modern Javascript framework for building modern, responsive, user interfaces. It is combined with Buefy (https://buefy.org/) that offers lightweight UI components based on Bulma (https://bulma.io/), and Leaflet, a JavaScript library for web mapping applications. We use Vue I18n internationalization plugin to support translation to different languages and localization (such as datetime), and tooltips to provide online, contextual help. The generic map data is fetched from OpenStreetMap API. Default map tiles are fetched from the humanitarian map style (http://map.hotosm.org/) which is focused on resources useful for humanitarian organizations and citizens in general, highlighting POIs like light sources, public and social buildings, …. Other tiling sources (e.g. transport map tiles) can be used at user convenience. On top of the map tiles, we display anchor markers, one marker corresponding to one user-created item. We use the Verbatim API to map an item address (as encoded by its user) to its geographical coordinates. Markers are colorized according to their corresponding *item type* (green for a donation, yellow for a loan, red for a request, and purple for an event). Current user location is displayed as a blue marker. A search bar allows the user to perform an address lookup (using Leaflet GeoSearch plugin) and moves the map to the corresponding location. In addition to user-contributed items, it is possible to display on the map other public free resources (such as public bookcases, community fridges, drinking water amenities, falling fruits, …) at their precise locations (as encoded in the OpenStreetMap or Falling Fruit databases) using markers with representative icons (from Wikimedia Commons). To add or edit these public resources, we integrated direct links with precise addresses to MapComplete (https://mapcomplete.org/), OpenStreetMap, and Falling Fruit editors (https://fallingfruit.org/).

As the number of map markers can be potentially large (e.g. there are almost 1.5M falling fruit and 250K drinking water locations worldwide), they are clustered thanks to the Leaflet Marker clustering plugin and displayed as one reach a certain zoom level in the map, which reduces the amount of data to transfer and to display. Going over a marker shows essential information (such as the item or public resource image, its type, a short description, and creator or source) while clicking on it will show full details and let the user starts a conversation with its creator, or associates a request to the public resource. In addition to the map, we also offer a "list view" of items with filters, following a listing-page design approach which loads content continuously as the user scrolls down (infinite scrolling). Similarly, users can get from there full item details and start conversations. In the Conversations tab, conversations are grouped by items. This module has been significantly modernized compared to (Guilliams, 2023). It now enables interactive chatting and allows text search to filter conversations.

Back-end

The back-end regroups everything that takes place on the server-side of the application. It relies on the Django framework written in the Python programming language. It describes how objects interact with each other (the "business logic" of the application) and it defines the methods to filter, add, update, and delete these objects. To save and retrieve data into and from the relational database, Django provides an ORM (object-relational mapper) library that provides means to interact with the database and convert objects within the Python

programming language into relational data in the database, and vice versa. User-created items are obtained through API endpoints that implements filters on item fields (e.g. to retrieve only "Food" items published in the last five days within a five kilometers radius), users (e.g. to retrieve only items created by a specific user), or title/description (e.g. to retrieve only items which have "cherry tomatoes" in their textual description). The API endpoint for items implements a pagination mechanism to enable progressive loading of large numbers of items, such as with infinite scrolling in the "browse items" front-end page. In addition to user contributed items, we call OverPass API to import OpenStreetMap data related to free amenities (and notify users when new public resources are created), and Falling Fruit API (https://fallingfruit.org/) to import free fruit locations. These external data sources are not explicitly stored in our database but retrieved (using current map location boundaries or neighborhood of the user's reference address) from the official OSM and Falling Fruit databases, so they are always up-to-date.

The messaging system (Conversations) is implemented using WebSockets (via Django channels) so that the Conversation module will refresh automatically to display new conversations and new messages, without the user having to explicitly reload the browser.

Database Model

We use a relational data model implemented using PostgreSQL (https://www.postgresql.org/). The data model determines the logical structure of our database where we store, organize, and manipulate data related to users, items, and conversations. We use PostGIS spatial extension (https://postgis.net/) to be able to perform operations on spatial coordinates, e.g. to compute the distance between current user position and an item. The distance is displayed in the item list, or used to filter items in the browse items listing page, or to notify users when a new item is created in their neighborhood. The Shareish conceptual data model is depicted by Figure 3.

Deep Learning for Item Auto-Tagging

Various approaches were evaluated in (Guilliams, 2023) to ease manual encoding of item metadata based on user-provided item images [Reqt 5]. These images are only transferred between the client-side and server-side of the application without using any external cloud services to preserve privacy [Reqt 9]. Deep learning models and computer vision workflows are automatically triggered by the back-end once a contributor associates image(s) to describe an item.

The first step uses a variant of a state-of-the-art deep learning model that is applied to predict the title of the item and infer its category. Compared to (Guilliams, 2023) where only a single image could be associated with an item, a user is now able to associate multiple images to an item. In this case, the model is applied to each image and term predictions are averaged. By default, the most probable term predicted by the model (among the 1000 nouns of the WordNet hierarchy used in ImageNet (Ridnik, Ben-Baruch, Noy, & Zelnik, 2021)) is then mapped to one of the 20 Shareish categories to automatically fill the first item category field. Users can choose another term from the list of the five most probable terms displayed in the item title dropdown, their choice being mapped into an item category accordingly. To further reduce manual encoding time, we applied in (Guilliams, 2023) optical character

recognition (OCR) techniques to detect textual elements in the uploaded item image hence auto-complete the item's description field. This was primarily designed for detecting the title of cultural items (e.g. books) or any other equipment whose name is visible (e.g. a household appliance). The analysis workflow is described and evaluated on books in (Guilliams, 2023). Here, it turned out to be interesting for other types of user content e.g. to analyze flyers announcing free events (e.g. a free market).

Because these auto-tagging approaches are prone to error and anyway users might want to add additional information about their items, predicted metadata are transferred from the back-end into the editable UI forms of the front-end. Hence, only user validated content is ultimately stored in the database.

Security

We implemented several security mechanisms such as HTTPS protocol, back-end URLs that can only be accessed by identified users (users will need to confirm their registration via email prior to being able to log in to the site), permissions (e.g. conversations are only accessible to the two involved users), and cross-origin resource sharing. User private information (such as names, e-mail, reference address) are not transferred to other users and only displayed in a user's own profile page for editing.

Deployment and Database Administration

As Shareish relies on various software technologies and because computing environments are heterogeneous (e.g. the server of a not-for-profit organization, the personal computer of an HCI developer, …), it is very important the design includes a reproducible, sustainable installation procedure to ease replication and updates of the platform [Reqt 10]. We use Docker Compose (https://www.docker.com/) container technology (Zhang et al., 2018) to encapsulate the software components. It eases the deployment of current and future versions of the Shareish platform, in two modes: local development mode, or production mode. Local development mode eases iterative development with hot reload mechanisms that allow software developers to change code locally and directly see their changes on the instance deployed on their personal computer. Communities will use the production deployment mode where Docker technology is combined with nginx proxy server (https://nginx.org/) to install the platform on a server and make it available straightforwardly to intended users through a web browser or mobile phone [Reqt 1,10].

If necessary, database content of a Shareish instance can be managed by logging into the database container, or more conveniently by using the Django admin module. This module reads Shareish data models and automatically provides a web user interface where trusted users (e.g. community moderators) can manage content [Reqt 9,10] using CRUD operations (create, read, update, and delete). A backup procedure has been implemented to safeguard the database content (including user and item images).

Actual Deployment of a Shareish Server Instance and Screenshots

We received approval from the GDPR office of the University of Liège to deploy a research demonstration server. A Shareish demonstration instance has been successfully deployed (https://shareish.org). The automatic installation procedure using container technologies takes about 10 minutes and includes automatic download of all libraries/modules, automatic build of front-end, back-end, database, and backup container images. Then, the automatic procedure to start all the platform containers takes about 1 minute. The same installation procedure has been tested several times on 7 different servers/laptops of our team members to assess portability and reproducibility. Thanks to the use of technologies described in the prevoius section, the technological burden is significantly reduced [Reqt 10] with respect to traditional deployment techniques where many manual configurations have to be set to run such a platform on a new host server. In terms of software maintenance, third-party organizations are able to install future versions of the platform by fetching the latest source code from our centralized repository. Then, the installation procedure consists in automatically rebuilding container images and applying database migrations (while keeping user data) as these operations are configured to occur automatically on startup. Our architecture (including back-end database and front-end mechanisms such as chunked loading and clustering) was designed to scale and it is robust enough to display a large number of items efficiently.

Since the end of 2022, in addition to our team members, 140 users have created an account (compared to 18 in (Guilliams, 2023)) following non-personal invitations on social media channels and advertisements directed to specific users from our professional and local networks. Thanks to the use of modern responsive design technologies, users have been able to successfully log in to and use the platform on various web browsers and mobile phones (Android, Windows, GNU/Linux, macOS, iOS). Some end-users created content (own items, events, or public resources, see Discussion) and provided various feedback that were translated into improved user interfaces. These changes have been continuously deployed on the demonstration server so that end-users were able to use different versions (iterations) of the platform. Readers are invited to test the latest version (Shareish v0.6 release at paper submission) and future releases deployed on our research demonstration server. The interactive Map page, the users interfaces to add items (with auto-tagging) and public resources, the "browse items" listing page, the page to view details of an item, the conversation module, and the page for setting notification parameters are illustrated by Figures 4 to 10. Notably, the appearance of user interfaces has been modernized since (Guilliams, 2023).

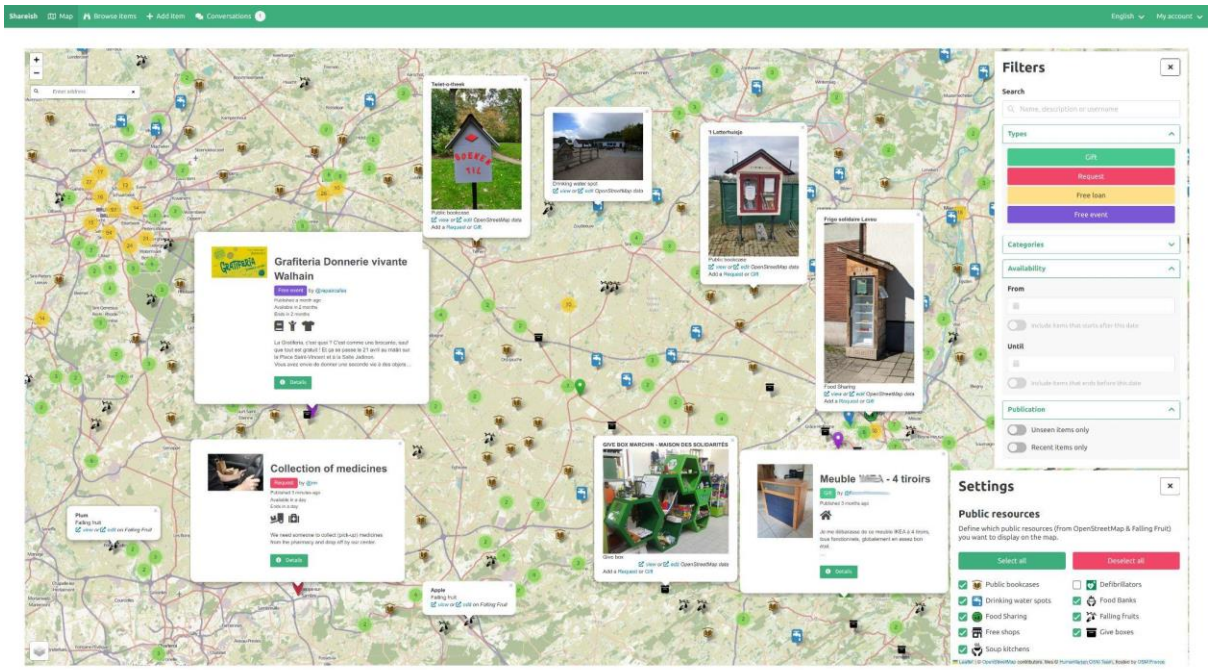

Figure 4. Shareish UI. Top: navigation bar with access to the map, the listing page, the add item page, conversation space (here: one unread message), internationalization, and account settings. Main view: the Map where users can navigate (zoom in/out, pan, locate), filter and select items, and enable/disable public resources. Here some content is selected on the map including a piece of furniture to give away, a free market ("*Gratiferia*"), a request for the pick-up and delivery of medicines, two public bookcases, a solidarity fridge, a give box, a drinking water source, two falling fruit spots (plum and apple). On the right, panels (which can be hidden) allow users to filter items and public resources.

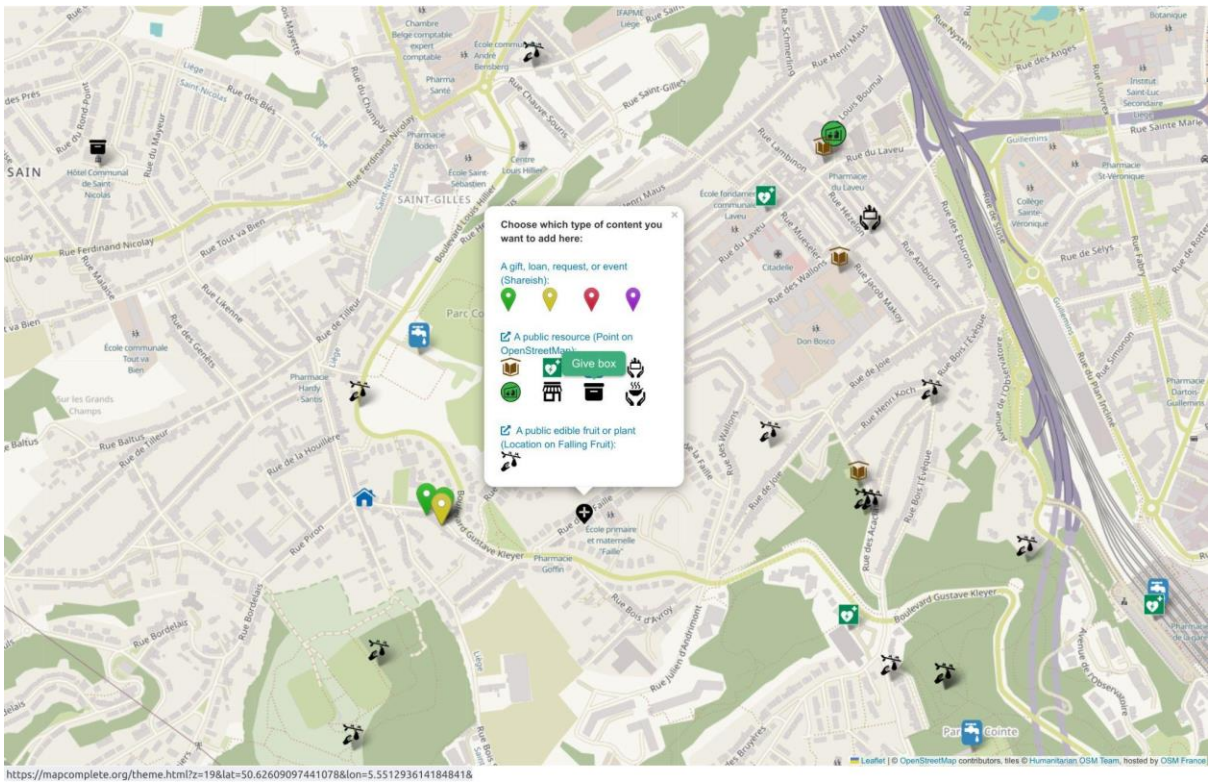

Figure 5. Shareish UI. A closer view of a neighborhood in Liège (Belgium) with a pop-up dialog triggered from a precise location on the map to add content (gift, loan, request, event, various public resources). Here, the user wants to add a give box with the precise GPS coordinates being automatically transferred to the public resource add module (MapComplete).

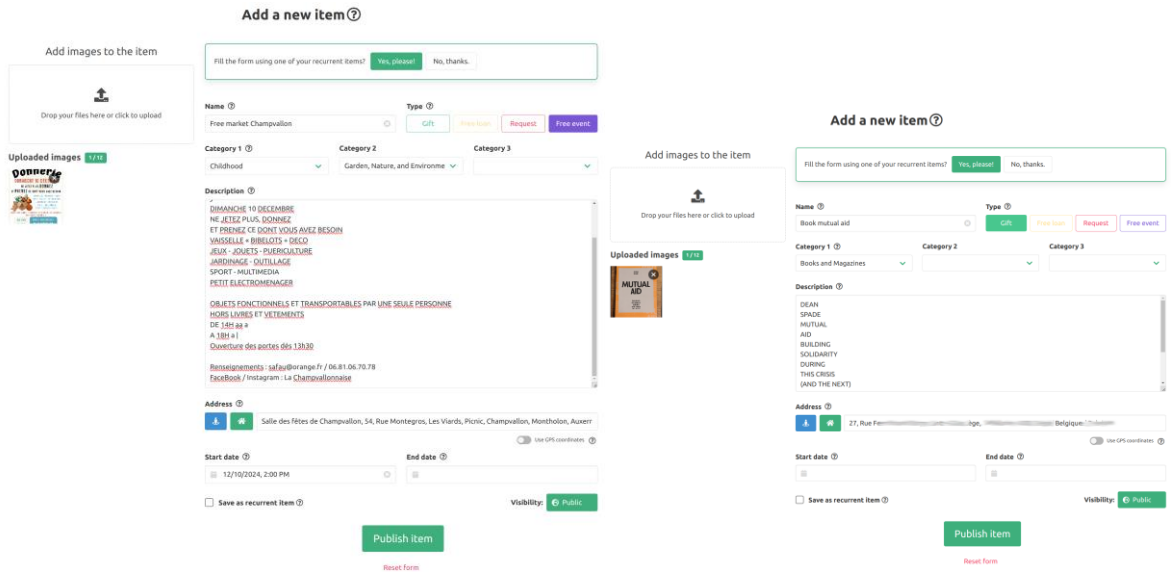

Figure 6. Shareish UI to add a new item. Left: A flyer announcing a free market is first uploaded by the user, with item Description being automatically pre-filled with text detected by the back-end auto-tagging module. Right: a picture of a book jacket with item Category ("Books and Magazines") and Description being automatically pre-filled. Users can edit all fields before (and after) publishing their item.

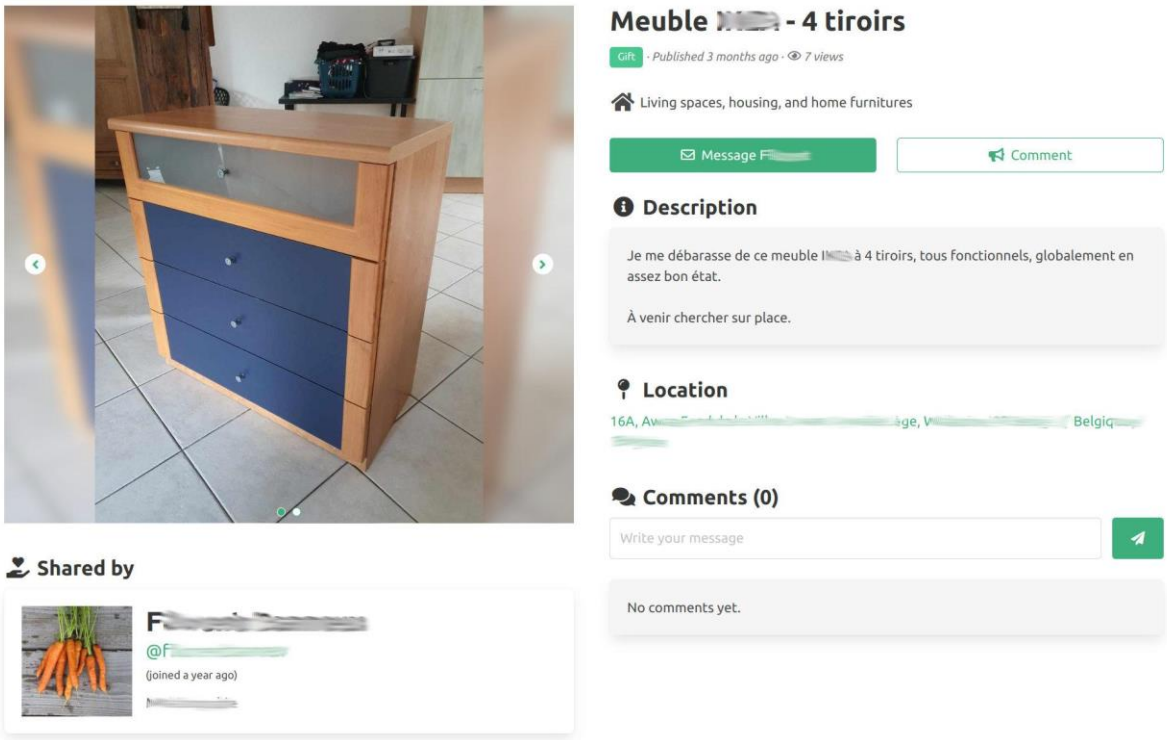

Figure 7. Shareish UI to view the details of a published item with Item image (left), type (Gift), title, description, and location (with direct link to the map); information about the giver (bottom left) and buttons to send a message (private conversation) or a public comment.

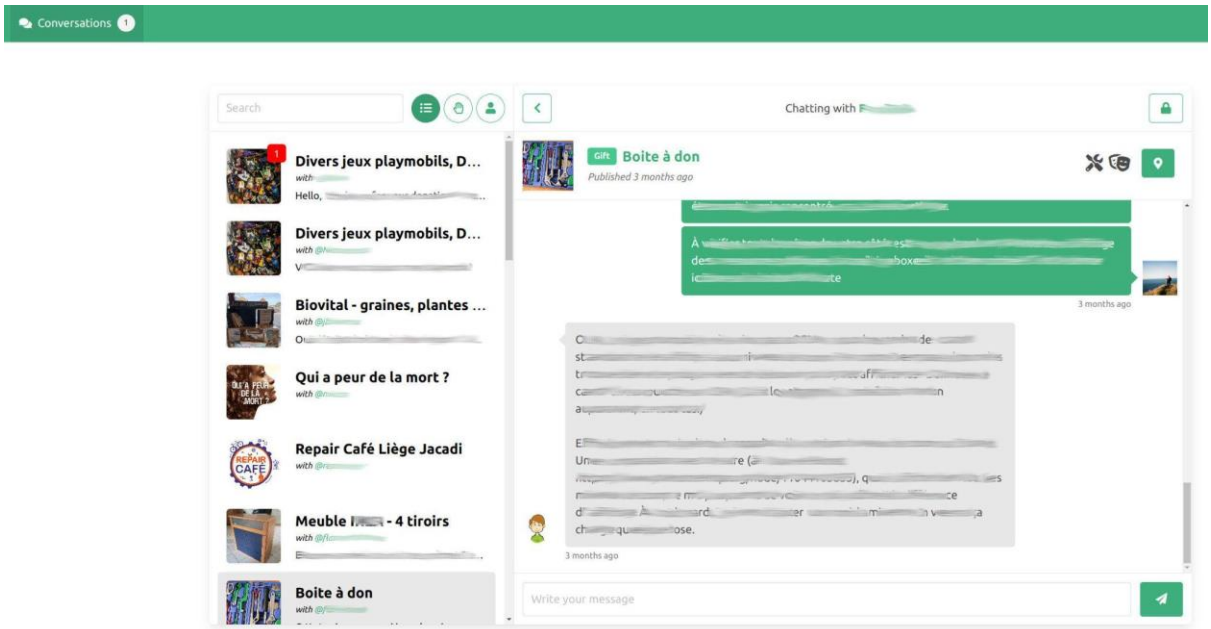

Figure 8. Shareish UI for online private conversations with list of open conversations on the left (including one unread notification), messages of the "boîte à don" conversation, button to lock the conversation (top right), and text field to send a new message (bottom). (Usernames and texts have been blurred for privacy)

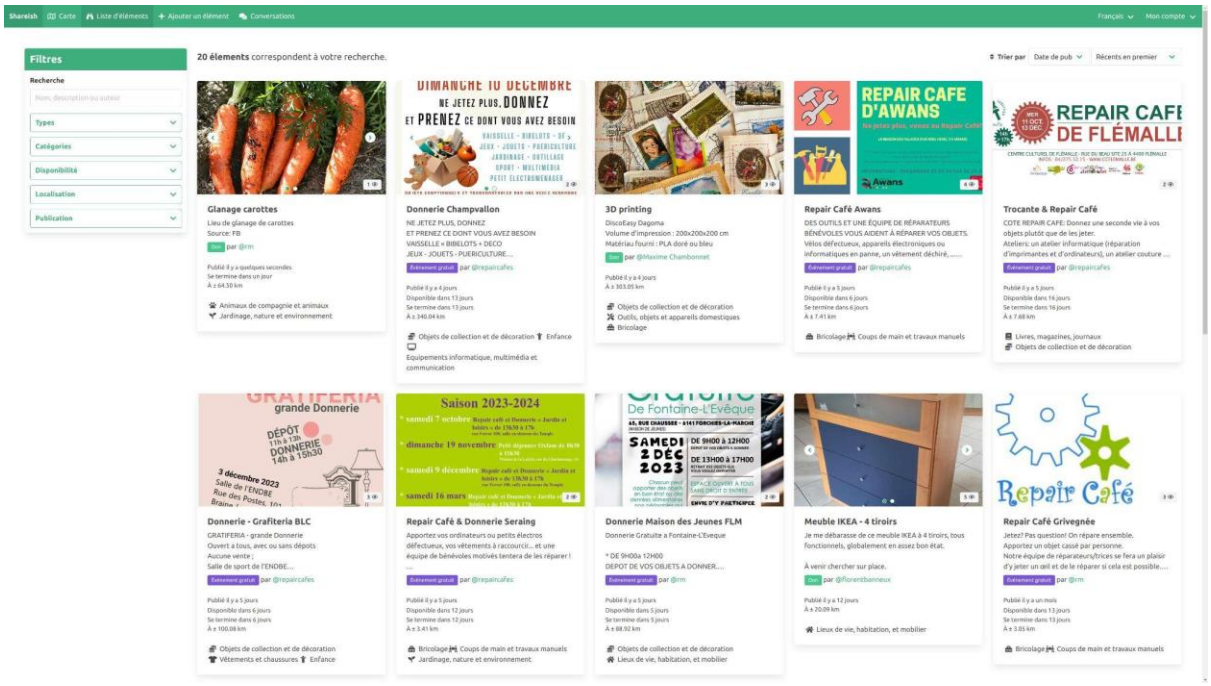

Figure 9. Shareish UI to browse items (listing-page). The list of items can be displayed according to the same search filters than on the Map page (here: none selected) and ordered (here based on publication date). Each item card shows the item image, creator, type, time frame, and categories; as well as distance from current position. The internationalization UI components allows to display the user interface in different languages and localization settings (illustrated here in French).

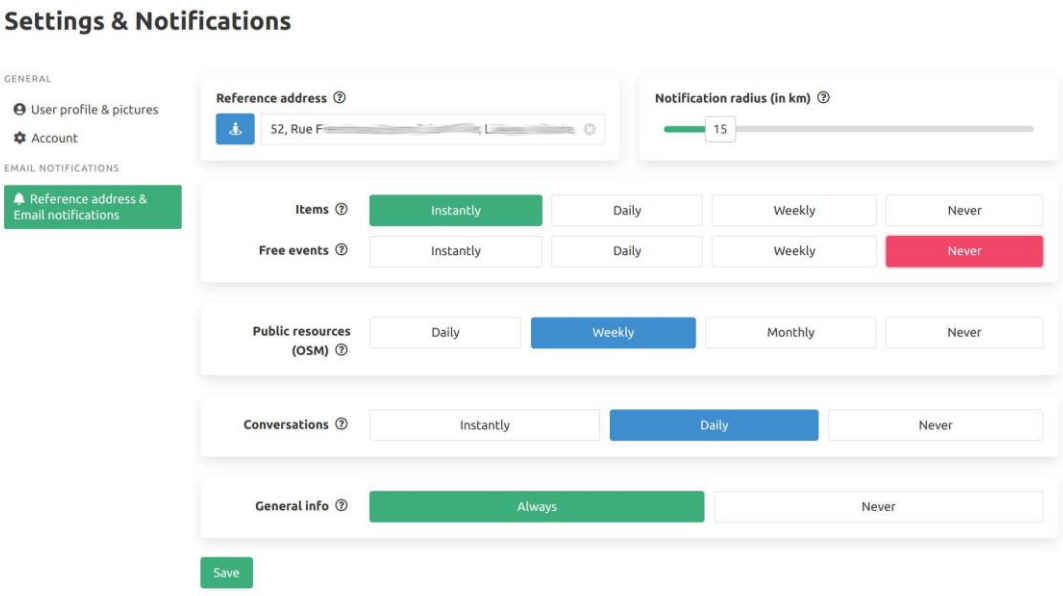

Figure 10. Shareish UI to configure notification parameters with the reference address and distance used to send notifications for new items, events, and public resources in their neighborhood; and the frequency of notifications (instantly, daily, weekly, monthly, never).

DISCUSSION OF LIMITS AND DESIGN OPPORTUNITIES

We have described our investigations of local solidarity practices and presented the extended design of Shareish's interactive system with the aim to facilitate a diversity of solidarity practices (including generalized exchange with face-to-face interpersonal exchange; gifting with no in-person contact through physical intermediaries such as in stooping or through the use of give boxes or public bookcases; free shops, or community fridges; gleaning or foraging, announcements of events such as free markets or repair cafés,...). We interviewed organizers of online and off-line solidarity communities, and conducted observations of online members. As we observed, actors have developed through the years some complex know-how to facilitate their operations. While Shareish echoes some of these processes, we will continue to endeavor to adapt itself to learn from these actors. A long-lasting influence should be sought by increasingly disseminating the tool, conducting additional in-depth case studies and by bringing together various stakeholders and involve them more directly in the development of future versions of Shareish. Our present qualitative study mostly focused on organizers, but more empirical research with members of sharing communities should be a priority in the future, as well as collecting feedback from actual and future users of the proposed platform. As we have observed on large online groups, there are very different participation frequency profiles. Our next qualitative investigations involve seeking participants of peer-to-peer exchanges for more in-depth interviews e.g. to understand the barriers to more frequent involvement in solidarity practices. While short-term techno-fixes are not a panacea (Morozov, 2013; Segal, 2017), it may happen that some barriers can be removed by adjustments. It was interesting to note how the welcoming appearance of the front window of a free shop could be used as a tool to convince outsiders to enter the shop (hence discovering the solidarity concepts behind it) as the free shop was regularly confused with any other commercial shop. In the same spirit, our user interfaces were designed to make non-monetary exchanges at least as user-friendly as commercial transactions on popular e-commerce and sharing platforms. Further improvements to enhance Shareish accessibility to a public less technologically inclined could certainly be developed. For example, some users suggested that creating a Shareish-specific account should be avoided to limit the multiplication of accounts, so single sign-on through existing social media accounts should be implemented to remove that barrier. We have identified other design issues, e.g. arising from the fact that we allow different types of content to be added as two different users wrongly used the add item user interface to add public resources (give boxes). Other technical and practical limitations might appear as the platform reaches more people from more diverse communities. This includes the fact that network connection might be unstable or limited in some world areas which would require improving the dependency on external servers (e.g. to get map tiles and public resources) and to implement local update and caching mechanisms to improve the resilience and responsiveness of a local Shareish instance. In terms of user experience, while Shareish is accessible on mobile phones as a progressive web application (it is delivered through web technologies to provide a user experience similar to a platform-specific application), developing a native mobile application could improve performance and usability. Modules to detect spams, bot flooding, inappropriate content, or aggressive messaging, might also be necessary to better protect users and communities against any threats. With the aim of identifying further platform limitations and continuing to

improve the tool, co-design and co-creation events are envisioned with various citizens and stakeholders of post-industrial cities within the context of a European project (UNIC "City Labs").

Following our interviews and online observations, we identified other design opportunities related to logistics, governance issues, and public communications. In terms of logistics, both free shop actors have mentioned that gifts could be possibly collected in a more efficient way and on a larger scale as surpluses (e.g. of unused clothes) are numerous. While Shareish user interfaces enable users to add requests (e.g. to pick-up items at a given location, or to request restocking a community fridge) and let users communicate through private conversations or public discussions, new software modules could be proposed for a more effective organization of such activities e.g. to collectively plan pick-ups and drop-off trips (including scheduling and routing), as observed in community fridges initiatives where simple online tabular sheets and posts on social media are sometimes used to organize the sharing of surplus food. Similarly, public resources are dynamic and we observed some communities have tried to combine various online tools to collectively check their status (e.g. to check the cleanliness of a community fridge). Such ideas and implementations from food sharing projects could be investigated and possibly adapted to other solidarity practices (e.g. free shops, give boxes, or public bookcases) (Berns, Rossitto, & Tholander, 2023). In terms of governance, we observed various conceptions, rules, and consequences related to topics such as free riding (e.g. reselling a good, obtained for free, outside of the community) or unreliable behaviors (e.g. missing an exchange appointment, or publishing false information related to unauthorized gleaning). Each community has its own set of rules (or absence of), decision processes, and ways to react. Interactive software modules to prevent unwanted behaviors could be investigated (e.g. a screen asking the user to confirm that they have the farmer's agreement before publishing a gleaning location). In parallel, software modules to establish, publicize, and implement community agreements could be envisioned to ease participatory democracy practices and collective organizing (Ruth, Prichard, & Swann, 2023) related to solidarity practices and public resources. In terms of public communication, some organizers might be interested in gathering usage statistics (e.g. the number of given clothes is marked with chalk on a free shop wall, or the size of a Facebook group is used to lobby for access to municipal buildings). Software modules could similarly gather platform usage statistics (conditional on user consent) and user feedback as a tool to assess and communicate their impact, justify their efforts, increase volunteer's motivation, or request support from public institutions. By regrouping and quantifying diverse, individual and collective solidarity practices, new Shareish software modules could offer more visibility to these initiatives, a better overview of their impact, and potentially inspire other initiatives. That being said, it will also be interesting in future work to take into account the digital divide (groups or individuals may have limited access to the Internet or different levels of digital literacy), to remember that the massive use of digital technologies is not neutral in terms of ecological impact, and that complex conditions or community issues are not necessarily best addressed with software technology (Baumer & Silberman, 2011; Morozov, 2013; Kidden, Strohmayer, & Yee, 2023; Sharma et al., 2023). If they succeed in fostering social ties between neighbors and if they contribute to multiplying the number of physical locations of exchanges and making them more visible, sharing platforms like Shareish may ultimately lead to a reduced reliance on energy-intensive technologies in the future.

Our qualitative study clearly underlines that such a software tool can not be implemented in a void but rather will be conditioned by the community in which it is applied, as there is no one-size-fits-all software program. In order to enable replication and local adaptation by groups seeking autonomy (Keyes et al., 2019), the platform is distributed under an open-source permissive license. Overall, we believe open source licensing and development is a necessary but most probably not sufficient condition for the sustainability of such a project "in the wild". Although free open-source licenses are irrevocable and therefore an open-source licensed software code will remain available for others whatever happens, the evolution of an open-source project is fragile (as individual coders come and go), and its governance is not straightforward (Lejeune, 2011b). Furthermore, local adaptations and a multiplication of self-hosted, distributed, server instances could make it more challenging to collectively organize a community of developers beyond the initiators of the project. To alleviate these concerns, different complementary approaches can be considered (Viorres et al., 2007; Coelho & Valente, 2017; Avelino, Constantinou, Valente, & Serebrenik, 2019; Poderi, 2019; Hamm, Shibuya, Ullrich, & Pargman, 2021; Ait, Izquierdo, & Cabot, 2022; Knutas et al. 2022; Qiu et al., 2023) including further sharing development tools and practices online to favor open participation, improving tool's interoperability, coordination and communication strategies to increase participation and maintain open source community dynamics by involving facilitators.

CONCLUSIONS

In this paper, we proposed an extended description of the motivations and of the technical implementation of Shareish (Guilliams, 2023), an open-source (https://github.com/shareish), online, map-based, interactive system to facilitate diverse non-monetary solidarity practices. The platform was designed for 'human' rather than market needs with the objective to facilitate the people's ability to meet their own needs through new community relations. Our design methodology combined an extensive literature review, online ethnographic observations, and a qualitative study with solidarity local actors. The platform is ready to use and can be replicated and extended freely. For future work, we identified avenues for furthering the qualitative study and design opportunities related to organization of solidarity community logistics, governance, and public communication. Overall, our work might be reappropriated by various communities including grassroots movements, emergency response organizations, social researchers, and HCI & CSCW developers.

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Authors' Note

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ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN COMBATING ILLEGAL FINANCIAL OPERATIONS: BIBLIOMETRIC ANALYSIS

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Abstract: *Money launderers and corrupt entities refine methods to evade detection, making artificial intelligence (AI) and machine learning (ML) essential for countering these threats. AI automates identity verification using diverse data sources, including government databases and social media, analysing client data more effectively than traditional methods. This study uses bibliometric analysis to examine AI and ML in anti-money laundering and anti-corruption efforts. A sample of 746 documents from 477 sources from Scopus shows a 14.33% annual growth rate and an average document age of 3.51 years, highlighting the field's actuality and rapid development. The research indicates significant international collaboration in documents. The main clusters of keywords relate to the implementation of AI and ML in (1) avoiding fraud and cybersecurity, (2) AML compliance, (3) promotion of transparency in combating corruption, etc. Addressing ethical concerns, privacy, and bias is crucial for the fair and effective use of AI and ML in this area.*

Keywords: *artificial intelligence, machine learning, anti-money laundering, anti-corruption efforts.*

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INTRODUCTION

The swift advancement of cutting-edge technologies like AI, blockchain, cloud computing, and machine/deep learning is driving economic processes into new realms where traditional linear models, finite frameworks, and strict hierarchies become obsolete. Instead, new relationships, connections, and interdependencies continually emerge, which is a hallmark of quantum economics. Holtfort and Horsch (2024) even state thatin recent years, quantum economics has been developing alongside behavioural and evolutionary economic theories, applying principles of quantum physics, such as wave-particle duality and uncertainty, to solve economic problems. The integration of AI and ML into financial security is not only vital for combating illegal financial activities but also holds transformative potential across various sectors, increasing the efficiency of employing human resources, changing the focus of their utilisation from a monotonous detecting to an analytical and controlling one.Numerous articles assert that AI and ML models and techniques provide greater accuracy, transparency, and security across various analytical fields. For example, empirical results from Awe and Dias (2022) indicate that autoregressive artificial neural networks model offers advanced prediction accuracy compared to the traditional method.

Kuzior et al. (2024) found that while the rapid advancement and widespread use of digital technologies enhance oversight of economic activities, they also introduce new challenges related to the rise of cybercrime. Yarovenko et al. (2023a) affirmed that leading nations like the USA, China, Germany, France, and others are both targets and perpetrators of cyberattacks. Moreover, Yarovenko et al. (2024) revealed that social and regulatory factors impact illicit practices in developed countries more than economic and digital factors. Barbu et al. (2024) investigated the trends in scientific collaboration on tax evasion and tax. Vasilyeva et al. (2021) utilized Data-Mining techniques to study the effects of digitalization and the COVID-19 pandemic on the selection of AML approaches. Polishchuk et al. (2019) created recommendations for implementing a cooperative model to enhance the effectiveness of code-based SMART contracts by reducing costs through the automation of manual processes and mitigating legal risks using distributed blockchain technology. Dobrovolska et al. (2021) investigated the evolution and current state of money circulation worldwide, and particularly in Ukraine, in conditions of digitalization and the development of blockchain technology and digital currency.

Governments and regulatory bodies worldwide are placing increasing importance in combating financial crimes. Complying with anti-money laundering (AML) regulations and other financial security measures is an escalating concern for financial institutions. AI and ML technologies aid in meeting these regulatory requirements by offering more accurate and timely detection of suspicious activities, ensuring adherence to laws and regulations, and helping avoid costly penalties. For example, in the mid-1980s, the US Customs Service's Financial Division began developing a system to analyse Currency Transaction Reports. The Financial Crimes Enforcement Network established by the Department of the Treasury then developed the Financial Artificial Intelligence System to identify suspicious patterns in the Currency Transaction Reports database. In 1991, the Advanced Research Projects Agency funded further development of AI systems for combating money laundering, focusing on issues linked to terrorism and illegal arms sales rather than drug trafficking.

Additionally, intelligence agencies are believed to use AI-based techniques for specific types of pattern recognition and analysis related to national security. In 1994, the US Senate formed a subcommittee to investigate the application of AI tools for identifying money laundering. The study found that an electronic funds transfer technology was being used to illegally move money from the US to financial institutions abroad. Consequently, the subcommittee recommended utilising AI in three main areas: acquisition, analysis, and utilisation of knowledge and data (Jensen, 1997).

Androniceanu (2023) indicated a noticeable improvement in management, increasing economic efficiency and social perception of state authorities and governance processes. Consequently, developing and implementing policies for using digital instruments and AI in public governance and state/municipal services leads to the dynamic development of a government. Fülöp et al. (2023) highlighted the ethical concerns related to AI in accounting. According to authors finding, while most accountants who took part in the interview had a basic knowledge of AI, only a few fully grasped the concept. Nonetheless, all participants agreed on the importance of AI ethics and the necessity of regulatory bodies to oversee ethical legislation concerning artificial intelligence. Drăcea et al. (2024) proposed that enhancing governance and human development can advance budget transparency, which ~~in turn~~ can further improve governance and contribute to greater human development by ensuring the efficient allocation of public resources while also considering political factors. Orlandić et al. (2024) suggested that combining robotic process automation with AI and ML improves operational productivity, reduces costs, and increases efficiency in the public sector. Kuanaliyev et al. (2024) highlighted the necessity of adapting the public administration system to digital transformation's emerging challenges and opportunities (including AI and ML). Waldman (2024) discussed the limitations of state-run healthcare systems and advocated for a shift to more technology (AI line predicting, processes for payment confirmation, medical error reviews, and clinical guidelines) and a human-oriented (patient-controlled) model, highlighting its necessity and feasibility. The article by Bozhenko et al. (2023a) reviewed the arguments and counterarguments in the scientific discussion on improving climate finance transparency. It identified data gathering, reporting systems, and accounting and management systems as the main challenges to the formation of an effective climate fund monitoring system. The study's relevance lies in revealing that the largest receivers of global climate finance are countries with high corruption risks, poor human rights protection~~s~~, and low trust in law enforcement and justice systems.

At the international level, the Financial Action Task Force (FATF, n.d.) has emphasized the challenges posed by cross-border money laundering and terrorist financing, intensified by the globalization of financial markets. Criminals and criminal networks exploit regulatory differences across jurisdictions to move illicit funds. AI and ML technologies are pivotal in analysing vast amounts of cross-border transaction data and identifying patterns that could signal illegal activities. AI and ML technologies address the complexities of transnational financial crimes by tracking the flow of funds across borders, detecting anomalies, and alerting authorities,. Beyond their immediate impact on financial security, AI and ML foster international collaboration and information sharing, which is essential for combating illegal activities in a globalized world. Organizations like Interpol and Europol leverage these technologies to enhance their data processing capabilities, significantly improving the detection and analysis of global criminal networks.

Corruption, Money Laundering in Modern Economy

Acar and Kara (2023) concluded that corruption significantly influences trade efficiency , especially in developing countries. The study by Gasimov et al. (2023) found that in non-EU post-Soviet countries, the effect of corruption on economic growth is less pronounced in energy-rich countries than in their energy-poor counterparts. Djouadi et al. (2024) suggested that corruption might encourage investment in these regions in specific contexts and economic environments, particularly if ineffective bureaucratic and stringent policies hinder investment activities (by simplifying processes like acquiring permits, licenses, and access to financing, creating a predictable business atmosphere).

The problem of overcoming corruption is especially significant for Ukraine, as this challenge is identified by the European Commission as the main one on our path to the EU, especially against the background of constant scandals with public procurement, army supplies and bribery. Kovbasyuk et al. (2024) highlighted the lack of significant progress in combating corruption, the lack of transparency in many public administration mechanisms, and the exposed corruption schemes involving the allocation of international military and humanitarian aid and public defence procurement. That threatens the support of international donors and partners, damages Ukraine's reputation globally, hinders its progress towards EU membership, and considerably affects the conclusions of external allies. Bozhenko et al. (2023b) stated that 89% of Ukrainians see corruption as the second biggest challenge to the country's stability after the full-scale war. The findings suggest that while Ukrainian society believes it can tackle corruption, there is limited active engagement, with only revolutionary actions considered in critical situations.

Maile and Vyas-Doorgapersad (2023) specifically investigated the institutional causes of human misconduct within South Africa's public service sector. Kaya (2023) empirically demonstrated and theoretically validated that government behaviour in times of economic or financial crises influences the extent and frequency of bribery in Eastern Europe and Central Asia. Bartulovic et al. (2023) found that corruption assists money laundering, while money laundering, in turn, reinforces corruption. Promoting and improving transparency within the anti-money laundering system is essential, as greater transparency reduces the potential for corruption among all stakeholders involved.

The article by Utkina (2023) investigated the current role of financial monitoring in fighting and avoiding money laundering and corruption. The author argued that with the expansion of blockchain technology, the financial monitoring environment would undergo significant changes, leading to more efficient and successful strategies for preventing and addressing money laundering and corruption. Kuzior et al. (2022) used quantile regressions to study the impact of digitalization on economic transformations. It was found that the level of digital development, influenced by national cybersecurity and ease of doing business, affects countries' susceptibility to fraudulent schemes for legalizing criminal income. The studies by Zámek and Zakharkina (2024), Asare and Samusevych (2023), and Kozhushko (2023) aimed to use bibliometric analysis to identify trends and investigation areas concentrating on the effects of digitalization and transparency on national defence. The research explored how these factors could enhance transparency and combat corruption while presenting challenges to cybersecurity due to the greater availability of information, focusing on financial fraud, tax

instruments, and economic security. It summarised the content and conceptual aspects of research on the digitalization of the economy.

AI and ML in Prevention Financial Crimes

Beyond enhancing research and development, improving staff's education, and fostering their personal development, AI and ML's ability to process vast datasets and identify patterns has implications for financial security. For example, phishing attacks, synthetic identity fraud, business email compromise, and other threats exploiting human mistakes and vulnerabilities are increasingly complex and challenging to detect using traditional methods. Staiger (2023), a content specialist of the Association of Certified Fraud Examiners, noted that technology-enabled schemes, such as deepfakes and social engineering, using AI-generated voice and video for impersonating executives and manipulating financial transactions, are challenging to detect and prevent with conventional techniques. Thus, AI and ML applications in detecting sophisticated cybercrimes contribute significantly to ensuring not just financial integrity but also the overall resilience of digital systems.

AI and ML technologies have significantly improved the capability to detect illegal activities in real time by analysing vast datasets for unusual patterns, which helps avoid human-related mistakes. For instance, major financial institutions now use ML algorithms to observe transaction data in real time, flagging suspicious activities that deviate from a customer's usual behaviour. According to a white paper by Deloitte and UOB (2020), these systems have reduced the incidence of false positives, increasing the accuracy and speed of detecting genuine fraud attempts. One of the critical improvements in AI and ML is the development of adaptive learning models that can evolve with changing patterns of financial crime. These models can learn from new data or even mine the data about customer patterns from social media, open data or internal bases, etc., and update themselves to identify emerging threats more effectively.

A publication by McKinsey & Company's experts underscores how AI and ML technologies have significantly reduced false positives in anti-money laundering (AML) systems. Traditional monitoring methods often generate an overwhelming number of false alerts, requiring extensive human resources to review and resolve. By integrating AI and ML, banks, insurance companies, and other financial institutions can more precisely identify genuine suspicious activities. This improvement lowers the costs associated with manual investigations involving human resources and allows institutions to allocate their resources more effectively, ultimately decreasing operational expenses on their staff (Doppalapudi et al., 2022). Čejka et al. (2023) demonstrated effective screen change recognition with minimum incorrect negatives and adequate mistaken positives, highlighting the potential for increased automation in examining. The study suggested that these technologies could promote user-centric innovations across different industries.

Furthermore, FOCAL (2023) suggested that AI and ML systems can automate fraud detection, enabling real-time monitoring of financial transactions through analysing vast datasets to detect patterns indicative of fraud, such as unusual transaction volumes or atypical human spending behaviours. Financial institutions adopting these technologies have reported substantial reductions in the time and cost associated with fraud detection and investigation, offering a competitive advantage in a tightly regulated industry. Lăzăroiu et al. (2023) studied how crowdfunding and blockchain fintech operations leverage AI algorithms, cloud

computing, deep and machine learning, augmented and virtual reality, and big data analytics in mobile payment transactions. According to the authors' findings, these technologies enhance the speed and accuracy of detecting suspicious transactions. Lei et al. (2024) explored China's implementation of the Digital Currency Electronic Payment (DCEP) project that challenges the existing framework for monetary crimes and includes a new form of legal tender covering contracts, transactions, identity information, and much more. DCEP is designed to resolve several emerging challenges, such as expanding the range of legal interests impacted by criminal activities, redeveloping the components of monetary crimes, diminishing criminal law's preventive role, and complexities in distinguishing between concurrent crimes. Botoc et al. (2024) argued that Big Data had significantly revolutionised the fintech industry, allowing companies to enhance decision-making, analyse customer behaviour, and create innovative products like personalised investment portfolios, risk-based pricing, and fraud detection solutions. Roba and Moulay (2024) explored the risks that banks encounter and the strategies for managing these risks, employing the artificial neural network model for various classification and discrimination tasks among institutions. Druva Kumar and Senthil Kumar (2024) noted that the contemporary insurance industry integrates advanced technologies like AI and ML and focuses on appearing tendencies such as digital changes and a customer-centric approach.

As AI and ML evolve, their integration into global efforts against financial crimes promotes international collaboration, improving communication and cooperation between institutions, authorities, and nations. Therefore, this technological advancementextends beyond the security domain, contributing to a more transparent and trustworthy global financial system. The commitment to implementing AI and ML in financial operations underscores their importance in shaping a secure, equitable, and progressive future. Dabija and Vătămănescu (2023) argued that AI had become embedded in our daily lives, transforming industries such as healthcare, finance, and transportation. Bilan et al. (2022) shared a similar perspective, exploring the interaction between AI from one side and management, change, culture in organisation, and organizational development from another side. Some research, for example, an article by Piotrowski and Orzeszko (2023), provided suggestions on the exploitation of AI technologies in finance with a focus on the ethical side of using such tools by banks. Durica et al. (2023) sought to innovate in predicting financial distress by developing individual models and ensembles, utilising ML techniques. The study by Abid et al. (2024) is unique in that it introduced AI and technological competence as moderating factors in achieving the advantages of implementing personnel service. In the paper by Pouabe et al. (2023), the managerial impact of decision-making is demonstrated using various data and two artificial neural network techniques in analysing the company's operations. Sahnouni and Benghebrid (2023) advocated for organisations to find a cost-effective and accurate system that reduces the influence of individual human prejudices during evaluations by adopting an innovative approach, improving objectivity, especially in complex systems. Skrynnyk and Lyeonov (2023) discussed that Big Data, Blockchain, and AI have similar applications in financial control and accounting in governmental authorities and commerce enterprises. They noted similarities in technical specifications like cryptocurrency, but differences in specific areas such as social networking problems in public services.

AI and Chellenges of Human Behavior and Data Sensivity

Managing sensitive human and financial data is a significant concern when using AI and ML to combat illegal financial operations. Guaranteeing data privacy and security while retaining the efficiency of these systems is a critical challenge. The paper by Höller et al. (2023) explored public awareness regarding unethical artificial intelligence and the actions that can be taken to counteract it (mitigation measures). The empirical findings indicated that an individual's awareness of improvement is induced by their self-efficacy, whereas trust in the algorithmic platform is of no significant influence. The most suggested mitigation measures include laws and regulations, algorithm audits, and education and training. Sheliemina (2024) argued that the application of AI in medicine comes with risks concerning ethics and data privacy, issues with the quality of data applied for learning procedures, and the need to protect against cyber threats. Additionally, there is a concern that medical costs may increase due to the extensive testing and validation required for new technologies. Dobrovolska et al. (2024) emphasised that the expansion of health digital databases and sites containing data on patients, hospitals, and medications, along with the increased use of remote access tools in healthcare, the rapid growth of telemedicine, especially during the COVID-19 pandemic, and the advancement of big data-driven cure technologies, such as computational oncology, necessitate robust cybersecurity measures. It is essential for clinics to safeguard the personal information, and for hospitals and health insurance companies to safeguardthe financial information, , guard patient records against cyberattacks, and guarantee fastened data exchange within the public health sector.

Behavioural analytics, powered by AI, can detect unusual behaviours that may indicate illegal activities. This includes the analysis of transaction patterns, frequency, and volume, which can reveal money laundering attempts or the financing of illegal operations. Oe and Yamaoka (2023) measured the effects of individuals' behaviour and interactions in the digital environment on altering personal behavioural models in the real world. Yarovenko et al. (2023b) proposed an approach to modelling the potential actions of insider cyber swindlers in banks. The study revealed that potential insider cybercriminals in banks are primarily interested in obtaining clients' personal financial information, accessing their online banking profiles, and acquiring their phone data. Ballester et al. (2023) examined how followers' behavioural engagement impacts word of mouth and the intention to participate in an activity, focusing on the moderating role of consumers' attitudes towards using unique tags in posts. The study's research model was tested using a sample of followers from the social media accounts managed by the establishment. Urbonavičius and Degutis (2023) argue that digitalization shapes various economic behaviors that occur online or combine online and offline activities. Their findings reveal an indirect effect of the willingness to disclose personal data and shed light on how privacy risks influence decisions related to online and offline behaviors.

Continued research and innovation in this field are crucial for enhancing the effectiveness and fairness of AI and ML systems in financial security. Addressing these investigational gaps through more comprehensive and inclusive bibliometric analyses can provide a clearer picture of the current landscape and future directions in implementing AI and ML to combat illegal financial operations. It will also ensure that the research community and industry practitioners are better equipped to tackle the complex challenges of financial crimes in a rapidly evolving digital landscape.

METHODS

To better understand the scope of issues, both explored and underexplored, identified in the literature review, it is also recommended to perform a bibliometric analysis of publications in artificial intelligence and machine learning in combating illegal financial operations. Considering this, we formulated several key research questions:

RQ 1: Is there an increasing research interest in applying AI and ML to combat illegal financial activities?

RQ 2: What are the main findings and trends in research focusing on AI and ML's function in addressing illegal financial operations?

RQ 3: Has there been a shift in research focus towards a more detailed examination of specific factors influencing the use of AI and ML in combating illegal financial activities?

When detailing the research methodology, it is vital to focus on three primary sections: data collection, cleaning, and analysis.

Data Collection

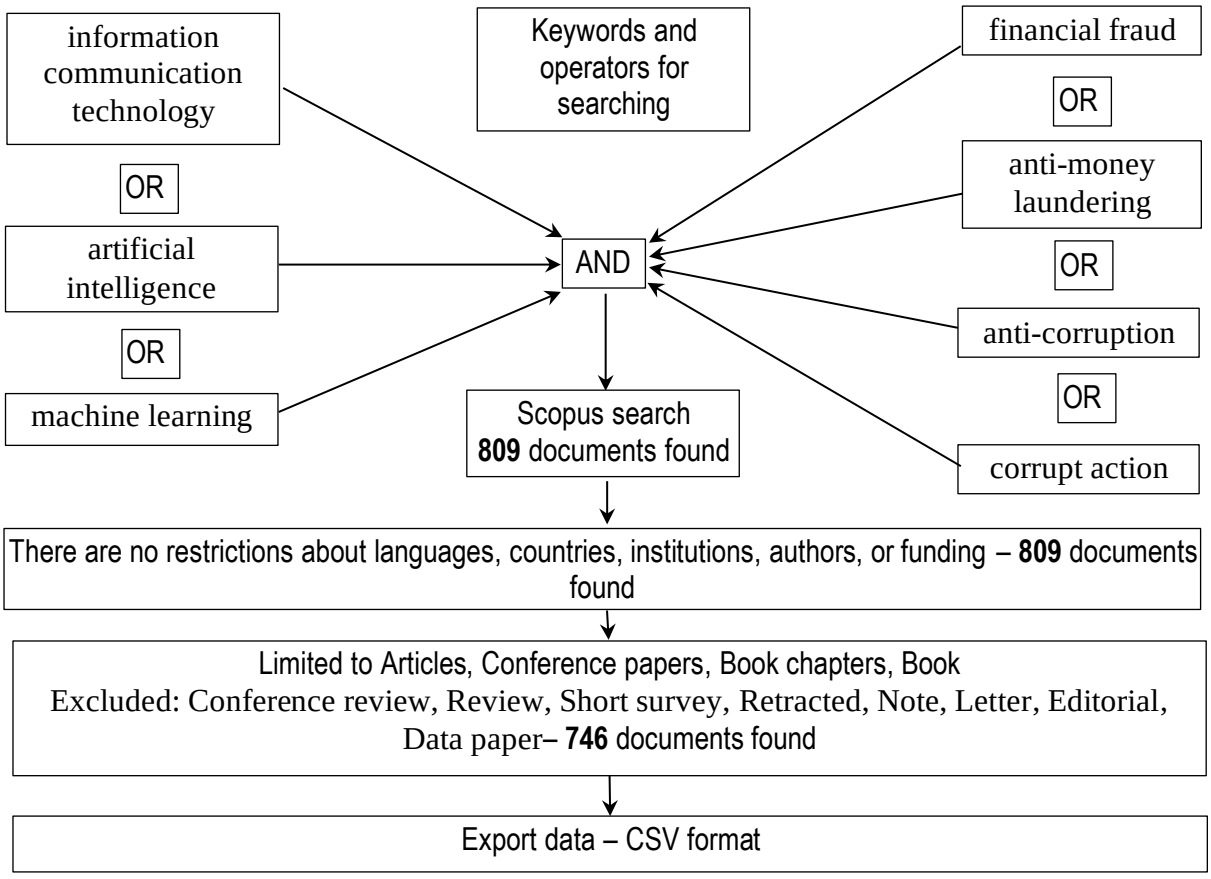


Figure 1. Data collection for searching in Scopus database documents with a focus on AI and ML's role in addressing illegal financial operations

Source: developed by the authors

Figure 1 is proposed to illustrate the data collection process, which utilises the Scopus database. Scopus is chosen for its extensive and comprehensive content coverage and its user-friendly interface, which includes individual profiles for authors, institutions, and journals. Its reliable impact indicators are less prone to manipulation and are obtainable for all sources (journals, proceedings of conferences, books etc.) in various scientific areas. Scopus stands out for its transparency and public accessibility, offering access free of charge to multiple metrics (Pranckutė, 2021). It also provides the convenience of accessing content through a single database, thus avoiding confusion and access limitations. Furthermore, Scopus enables operators to take search results in several formats, such as CSV, Bibtex, and Excel.

Data cleaning

The following keywords were excluded because they reference not precisely to the area of research but more to the characteristics of the sample for investigation (countries or their groups, or they pertain directly to the research methodology and reporting of results), that is not relevant to our objectives. Therefore, it was decided to exclude next keywords: logistic regression, xgboost, based, study, de, review, paper, research, results, authors, author, ieee, proposed.

The words listed below were recognised as synonyms, enabling their metadata to be combined during the analysis:

- information and communication technologies, information and communication technology, ICT, information technology;
- machine learning, machine-learning;
- machine learning algorithms, machine learning methods, machine learning techniques, machine learning models, learning algorithms;
- blockchain, blockchain;
- investment, investments;
- neural network, neural-networks, neural networks, neural-network;
- anti-money laundering, anti-money laundering (AML), AML;
- system, systems;
- technology, technologies;
- method, methods;
- algorithm, algorithms.

Data analysis

This investigation uses Biblioshiny and Excel to analyse and present gathered data from Scopus databases. Data from Scopus was first imported into Biblioshiny, and then each result was individually exported to Excel. As a result, 746 publications were analysed using bibliometric methods. Complete evidence about the quality of different metadata of the sample of documents with a focus on AI and ML in combating illegal financial operations and on the next stage used for the bibliometric investigation is presented in Table 1.

Table 1. Completeness of bibliographic metadata [Source: developed by the authors (based on the Scopus database using the Biblioshiny App).]

Metadata	Description	Missing Counts	Missing %	Status
AB	Abstract	0	0.00	Excellent
AU	Author	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
C1	Affiliation	5	0.67	Good
CR	Cited References	16	2.14	Good
DI	DOI	75	10.05	Acceptable
DE	Keywords	94	12.60	Acceptable
ID	Keywords Plus	254	34.05	Poor
RP	Corresponding Author	272	36.46	Poor
WC	Science Categories	746	100.00	Completely missing

The sample documents were selected from publications released between 1991 and the first half of 2024 (Table 2). According to Biblioshiny, these publications featured 2103 unique authors, including 85 single authors. These 85 authors published 89 single documents. Also, on average, more than three authors cooperated in research (indicator Co-Authors per Document is 3.31). Interestingly, almost half of all documents (49.06%) are conference papers.

Table 2. Descriptive Statistics of the Sample Publications [Source: developed by the authors (based on the Scopus database using the Biblioshiny App).]

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	1991:2024
Sources (Journals, Books, etc)	477
Documents	746
Annual Growth Rate %	14,33
Document Average Age	3,51
Average citations per doc	12,98
References	24133
DOCUMENT CONTENTS	
Keywords Plus (ID)	2893
Author's Keywords (DE)	1749
AUTHORS	
Authors	2103
Authors of single-authored docs	85
AUTHORS COLLABORATION	
Single-authored docs	89
Co-Authors per Doc	3,31
International co-authorships %	18,23
DOCUMENT TYPES	
article	315
book	6
book chapter	59
conference paper	366

RESULTS

Over the entire period 1991-2024 (it should be noted that for the year 2024, only the publications of the first half of the year are included) on AI and ML in combating illegal financial operations, it is possible to state that there is a growing number of publications with an annual growth rate of 14.33% (Table 2). At the same time, a significant part of the publications is dated in recent years, and the average age of the document is 3.51 years (Table 2). Analysis of the dynamics of publications allows us to distinguish the following three periods:

1) 1991-2002 - the periodic appearance of publications and the initial appearance of interest of scientists in the issues of AI and ML in combating illegal financial operation, although interest in the development and promotion in the practical plane was observed as early as the late 1980s, as mentioned earlier, FinCEN was instituted by the Department of the Treasury in 1988-89. Furthermore, the lack of scientific publications is surprising.

2) 2003-2015 – variable publication activity of authors in this topic with a growing trend, which has the form of an exponential equation $y = 1{,}3804e^{0{,}1532x}$, the coefficient of determination approaches 0.7 ($R^2 = 0.6797$), so we can assert about the high level of reliability of the obtained equation describing the trend (Figure 1).

3) 2015-2024 – rapid growth, which is described by the equation of the polynomial trend of the second-degree $y = 2{,}9286x^2 - 2{,}0952x + 9$, the coefficient of determination of the trend $R^2 = 0.9936$, which indicates the almost 100% reliability of the obtained forecast trend for 2024- 2026. According to this forecast, further rapid growth in scientists' publication activity on the analysed topic is expected. In 2026, the number of publications will reach the mark of 340 documents (Figure 1).

The oldest publication on AI and ML in combating illegal financial operations is an article by Sherizen (1991), which explored the influence of Unification '92 on information safety. While considerable effort had been concentrated on developing the assessment measures for information technology security by experts, further crucial yet indirect decisions about information security were being made. The outlined decisions regarding Unification '92 could be critical in shaping information defence after 1992. The author mentioned that numerous EC directives and outcomes, some not explicitly labelled as information security, will significantly influence the protections that will be feasible and required. The major categories of these include decisions related to the following: (1) to technical part (computer and communications technologies); (2) to legal resolutions and the definition in legislation of financial errors, crimes, and disputes; (3) to political and public policies related to the overall economy and the regulatory restrictions imposed on financial services operations, services, and products. The author also provided examples of these categories from critical European information services, auditing standards and constraints, anti-money laundering controlling systems, open boundaries, and electronic data intersection.

The following article on the subject under investigation appeared only in 1995. The article by Goldberg and Senator (1995) explained that databases often struggle to identify entities of interest accurately. To address this, two operations – consolidation and link formation – were proposed as crucial components for Knowledge Discovery in Databases (KDD) systems, complementing traditional machine learning practises that use clustering based on similarity. Merging and linkage arrangement can be efficiently implemented as index formation in

interactive catalogue organisation systems. An operational KDD system utilises these techniques to detect possible money laundering behaviours within a database of significant money operations.

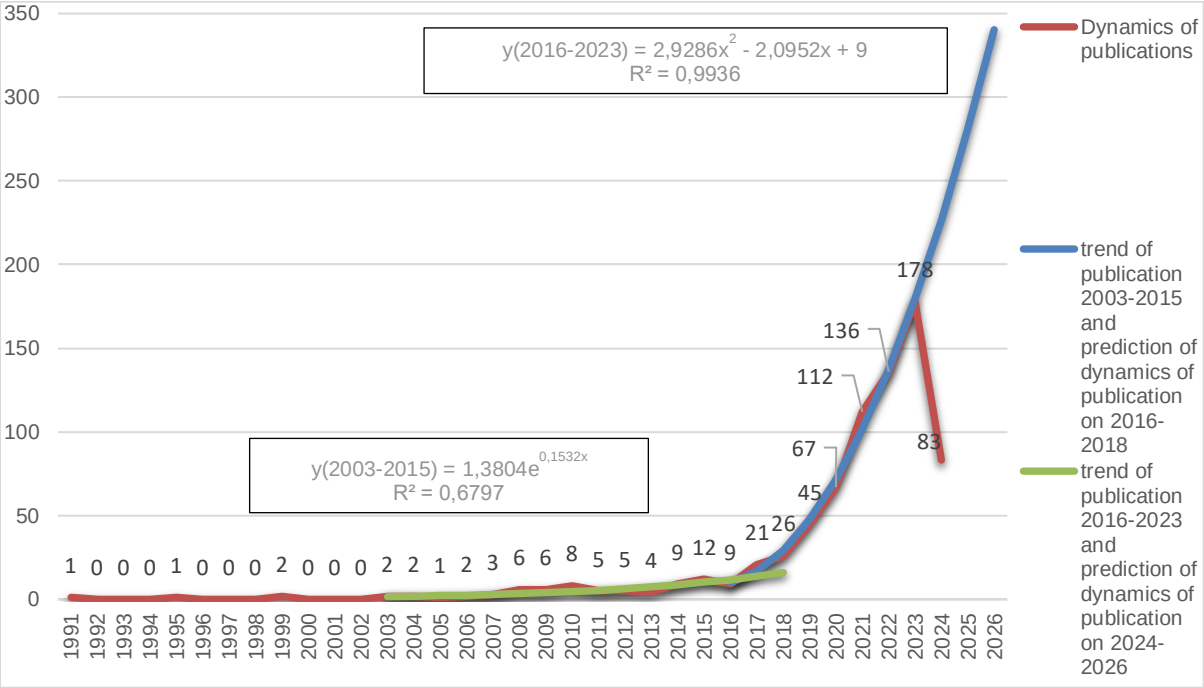


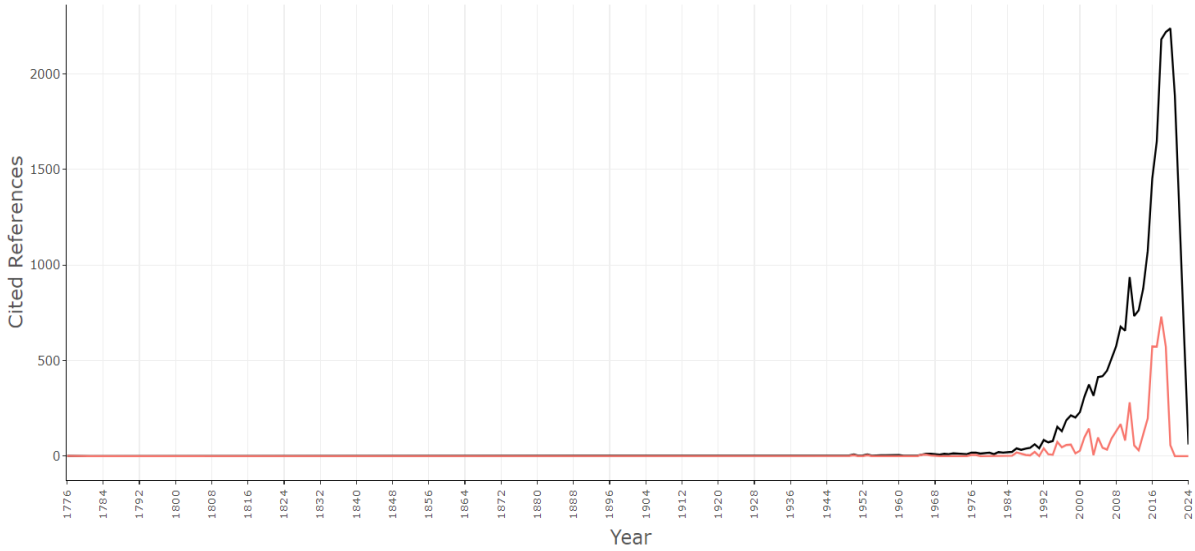
Figure 1. Dynamics and the trends of publication on the topic of AI and ML in combating illegal financial operations.
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)].

The most cited reference among publications on AI and ML in combating illegal financial operations is Randhawa et al. (2018), which explored using machine learning algorithms to detect credit card fraud. The study began with standard models and then introduced hybrid methods, including AdaBoost and majority voting techniques. The effectiveness of these models was evaluated using a publicly available credit card dataset, followed by testing on a real-world dataset from a financial institution. To further assess the robustness of the algorithms, noise was introduced to the data samples. The experimental results indicated that the majority voting method performs exceptionally well, achieving high accuracy in detecting fraudulent transactions. This reference had 21 local (among a sample of publications) citations.

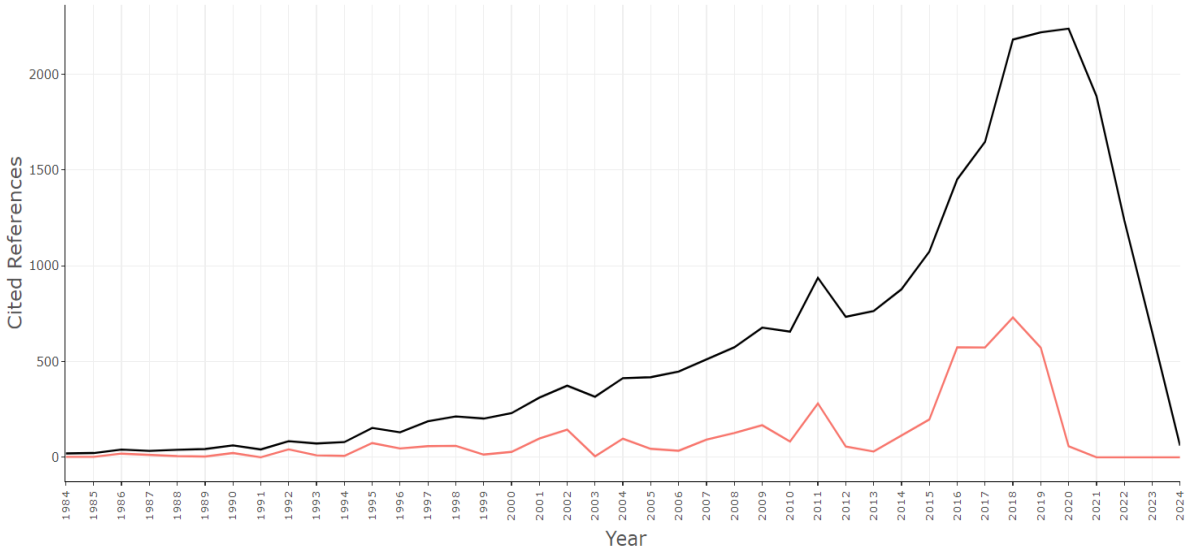
On the second position (20 local citations) is the article by Bhattacharyya et al. (2011), which equivalenced the efficacy of different procedures, including support vector machines, random forests, and logistic regression, in identifying fraudulent transactions to advance the detection, control, and prosecution of credit card fraud by evaluating and recommending the most effective data mining approaches. Using real transaction data from an international credit card operation, the authors also aimed to determine which methods provide the best effectiveness, considering accuracy and reliability.

Biblioshiny App allows for the building of reference spectroscopy to understand the peaks of a citation and to analyse their connection with events in that period. Figure 2 presents such

spectroscopy for the sample of publications on AI and ML in combating illegal financial operations.



a) whole period



b) 1984-2024

Figure 2. Spectroscopy for the sample of publications on the topic of AI and ML in combating illegal financial operations (Black – Number of cited references per year; Red – Deviation from the 5-year median)

[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

Among 2103 authors in our sample (Table 2), the most productive author focusing on AI and ML in combating illegal financial operations is Jingyu Li, a researcher from the School of Mechatronics Engineering of the Beijing Institute of Technology (Beijing, China). The other most productive authors (that published five or more articles) and the indicator of their fractionalised articles are presented in Figure 3.

Lotka's law is a rough inverse-square law, stating that the number of authors publishing specific articles is fixed to the number of authors publishing just one article. According to Lotka's law, as the amount of published articles rises, the frequency of authors producing that many publications decreases.

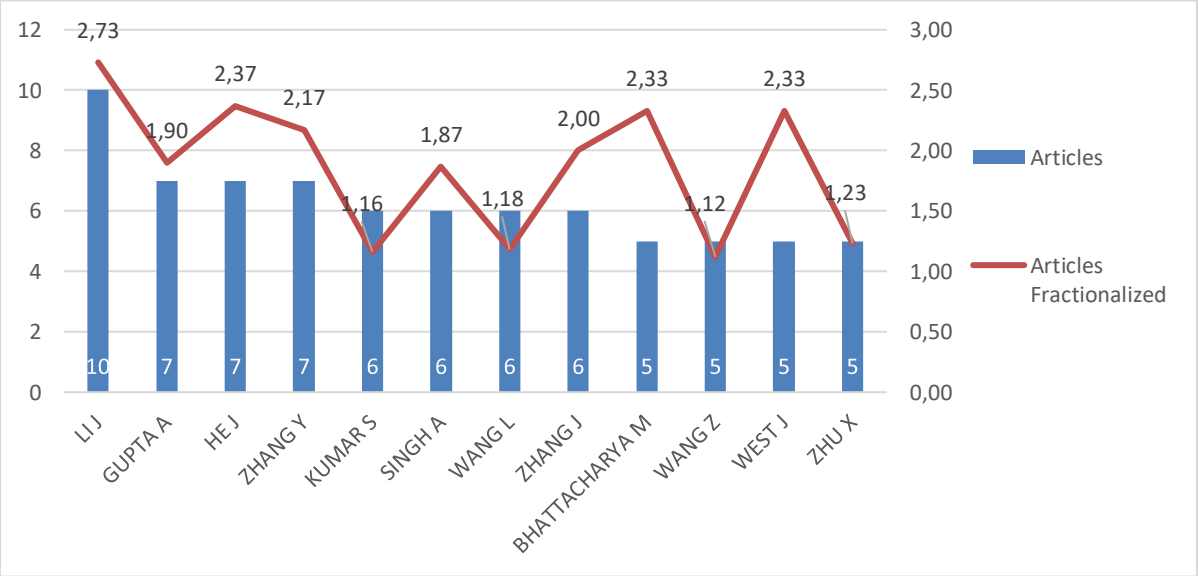


Figure 3. The most productive authors (that published five or more articles) and the indicator of their fractionalised articles.
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

In our case, there is only 1 (0.14% of all authors) author (Li J.) that published ten articles on the topic of AI and ML in combating illegal financial operations, three authors (Guptaa A., He J., and Zhang Y. – 0.14% from 2103 authors) published seven articles, two groups of 4 authors each (0.02% of all authors) published 6 and 5 articles, respectively, 45 authors (2.1%) published four articles, 144 authors (6.8%) have two articles in their portfolio.

Table 3. Authors' local impact [Source: developed by the authors (based on the Scopus database using the Biblioshiny App).]

Element	H_Index (Hirsch index)	G_Index	M_Index (H_Index/namber of year from first publication)	TC (Total Citations)	NP (Number of Publica-tions)	PY_Start Start Year of Publica-tions
He J.	6	7	0,353	128	7	2008
Singh A.	5	6	0,833	59	6	2019
Bhattacharya M.	4	5	0,4	64	5	2015
Gupta A.	4	7	1	62	7	2021
Jain A.	4	4	0,667	64	4	2019
Li J.	4	7	0,4	59	10	2015
West J.	4	5	0,4	64	5	2015
Chen Y.	3	4	0,6	19	4	2020
Gao S.	3	3	0,158	75	3	2006
Garcia-Bedoya O.	3	3	0,6	29	3	2020

Other 1880 (89.4%) authors have published only one article. We provide an analysis of the authors' local impact by calculating the indexes, including the H-index, G-index, and M-index, that characterised different sides of the citation of their articles (Table 3). He J. is the most influential author with the highest H-index, G-index, M-index, and total citations. Singh A. has the highest M-index (0,833) because this author started his scientific activity much later than He J (2019 against 2008).

Biblioshiny App allows the creation of a Sankey Plot by selecting three main meta-data fields. If we choose the top references, authors, and keywords, we can build the Graf by focusing on top authors, their intellectual roots (references), and research content (keywords).

The most cited «roots» among the top 12 authors are the following: Randhawa et al. (2018), Bartoletti et al. (2018), Bhattacharyya et al. (2011), Chen et al. (2018), Kirkos at al. (2007), Nakamoto (2008) were cited three times, others were cited once (Figure 3).

Almost all the top authors cited references from the top group. Still, two authors, Bhattacharyya M. and Zhang Y., did not refer to articles from the top group of references. This is explained by the fact that the articles of such author, Bhattacharyya M., are explanations because his research was included in the top group of references. However, the work of Zhang and Trubey (2018) is included among the top 30 references for the analysed topic (Figure 4). Regarding keywords, it is impossible to identify preferences among the top 20 authors (Figure 4).

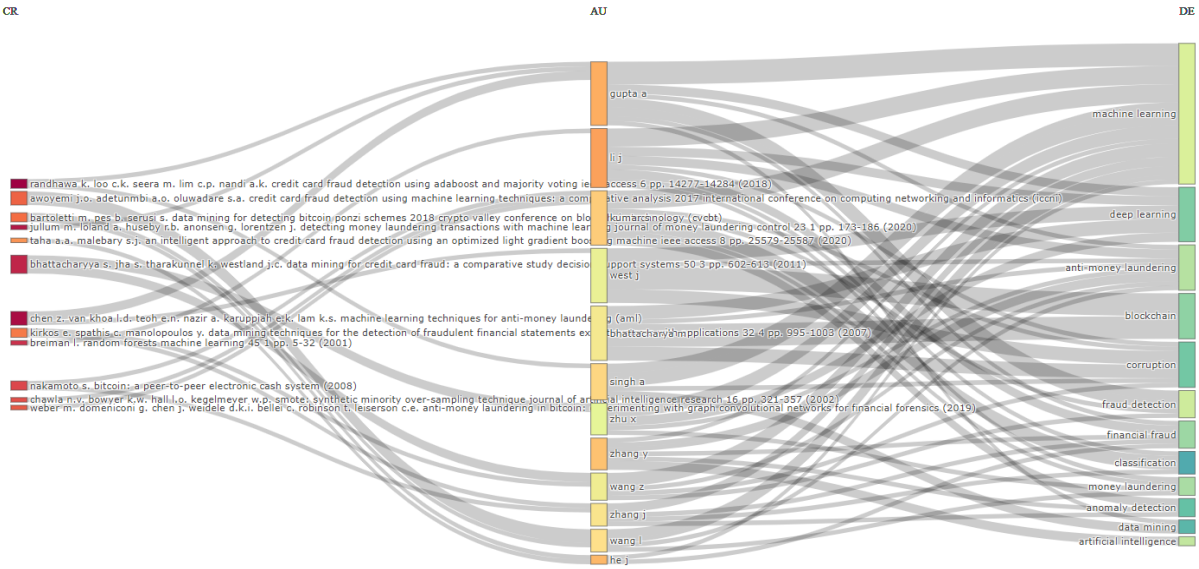


Figure 4. The three-field plot «References – Authors – Keywords" focuses on AI and ML in combating illegal financial operations.

[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

According to Table 2, international co-authorships are 18.23%, which means that almost one of the fifth articles is a collaborative investigation. Table 3 presents statistics on the output of scientists from various countries, measured by the number of publications. Only authors from top countries such as Canada, Bangladesh, and Brazil published single-country publications; others have worked in solid international cooperation. The highest level of MCP_Ratio is linked with the United Arab Emirates. The undisputed leader in the number of publications is China (12.9% of publications), and the top 5 countries also include India, the USA, the United

Kingdom, and Italy. The top 5 countries account for 32.7% of all publications. The top 23 countries (5 or more publications) account for almost 50% of publications (Table 4).

Table 4. Corresponding Authors's Countries (affiliated authors published five or more articles) and their affiliated author's publication activity characteristics. [Source: developed by the authors (based on the Scopus database using the Biblioshiny App).]

Country	Number of the articles	Single Country Publications	Multiple Country Publications	Ratio of publications within the sample	Multiple Country Publications / total number of publications by country
China	96	75	21	0,129	0,219
India	77	71	6	0,103	0,078
USA	29	22	7	0,039	0,241
United Kingdom	24	17	7	0,032	0,292
Italy	18	11	7	0,024	0,389
Australia	14	11	3	0,019	0,214
Malaysia	10	8	2	0,013	0,2
Canada	9	9	0	0,012	0
Germany	8	6	2	0,011	0,25
Korea	8	7	1	0,011	0,125
Poland	8	7	1	0,011	0,125
Saudi Arabia	8	5	3	0,011	0,375
Spain	7	6	1	0,009	0,143
Greece	6	5	1	0,008	0,167
Morocco	6	5	1	0,008	0,167
Turkey	6	5	1	0,008	0,167
United Arab Emirates	6	2	4	0,008	0,667
Austria	5	2	3	0,007	0,6
Bangladesh	5	5	0	0,007	0
Brazil	5	5	0	0,007	0
Colombia	5	3	2	0,007	0,4
Netherlands	5	3	2	0,007	0,4
PortugalP	5	5	0	0,007	0

Biblioshiny allows the building of countries' collaboration networks. In the red cluster, India is leading with the Betweenness indicator (198.176). Interestingly, authors from other countries of the red cluster cooperate actively with authors from other clusters. The closest connection in the blue cluster is observed between the authors of the USA and the UK (Betweenness is equal to 176.704 and 103.844, and the closeness of both countries is equal to 0.15). The authors of these countries are also closely connected with China (Betweenness is 96.539, and closeness is 0.13). The authors of the only country of the turquoise cluster are related to the USA. Similarly, authors from Indonesia (grey cluster) and Mexico (orange cluster) are linked by co-publications with authors from Malaysia. It should be noted that the authors of the purple cluster (Ukraine and Kazakhstan) and the brown cluster (Cyprus and Iran)

have joint publications exclusively among themselves and are not connected by joint publications with authors from other countries (Figure 5).

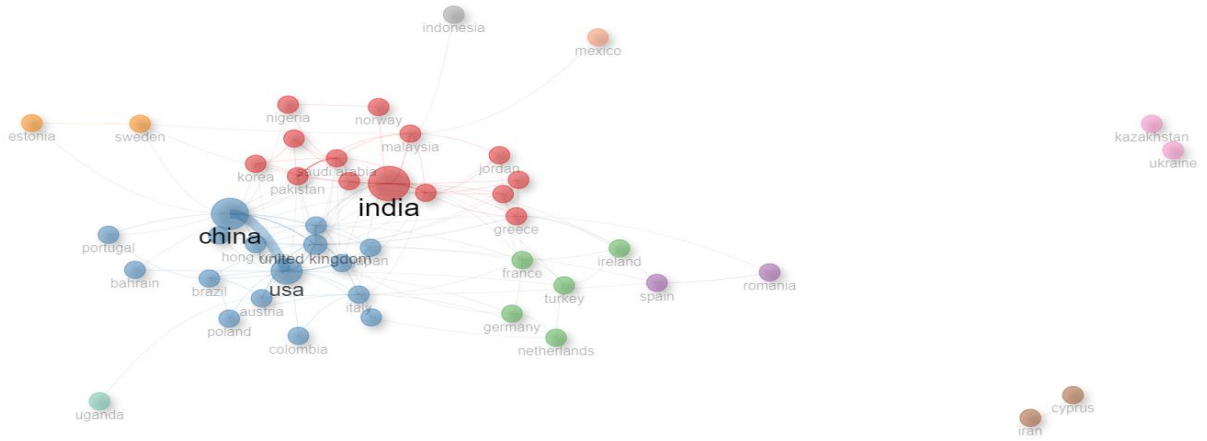


Figure 5. Collaboration network of the countries
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

Biblioshiny allows the building of Sankey Plot based on the top countries, affiliated institutions, and authors (Figure 6). We can state that most institutes cooperated with authors from several countries. So, Politecnico di Milano employed authors from Italy, the USA, and the UK. Although there are institutions affiliated with authors from only one country, for example, Sun Yat-Sen University is linked only with authors from China. Just some top 20 institutions collaborated with authors from the top 12 list (those with five or more publications). Only Hunan University of Finance and Economics, Sun Yat-Sen University, University of Electronic Science and Technology of China, and Tongji University have experience in employing such authors (Figure 6).

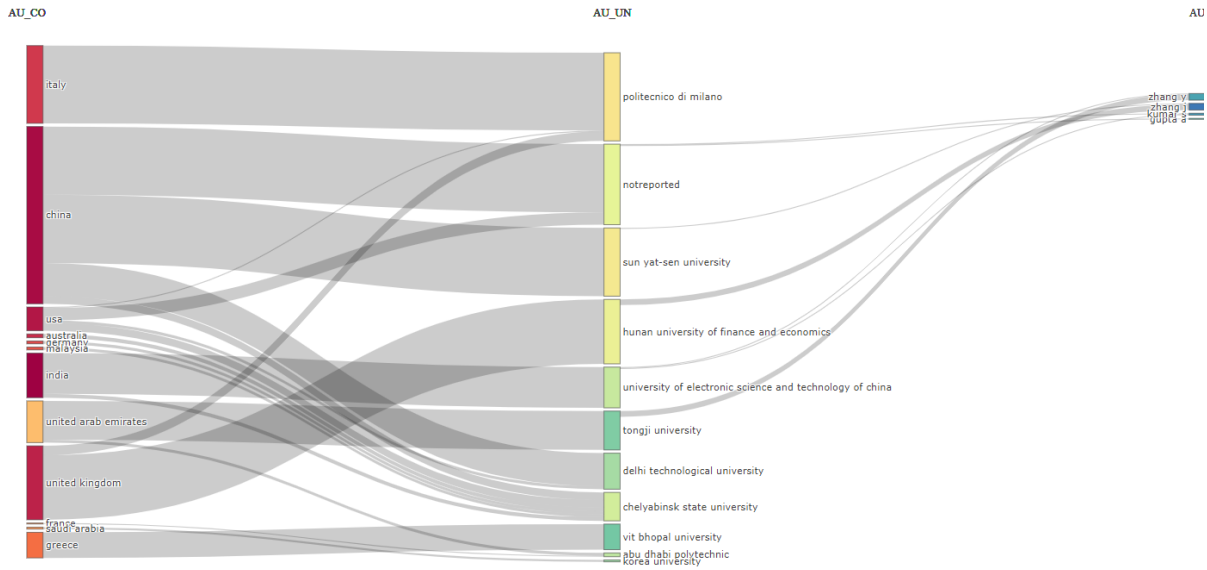


Figure 6. Three-field plot «Countries – Institutions – Authors».
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

From our sample of 477 sources (Table 2), the top 15 sources are mostly conference papers. Table 5 presents the top 15 sources in the sample of publications focusing on AI and ML in combating illegal financial operations.

Table 5. The top 15 most relevant sources [Source: developed by the authors (based on the Scopus database using the Biblioshiny App).]

Sources	Articles
ACM International Conference Proceeding Series	23
Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	20
IEEE Access	19
Lecture Notes in Networks and Systems	17
Procedia Computer Science	14
Communications in Computer and Information Science	13
Journal of Money Laundering Control	13
Advances in Intelligent Systems and Computing	12
CEUR Workshop Proceedings	12
Proceedings of the ACM SIGKDD International Conference on Knowledge Discovery and Data Mining	8
AIP Conference Proceedings	7
Expert Systems with Applications	7
Journal of Financial Crime	6
Lecture Notes in Electrical Engineering	6
Proceedings - 2022 IEEE International Conference on Big Data, Big Data 2022	5

Bradford's law states that consecutive zones of journals with the same number of articles on a particular topic create a simple geometric series. The three categories or «zones» of journals are (1) journals that provide the weightiest insights into the topic, which include 35 items in this case; (2) sources that make occasional but noteworthy contributions, totalling 196 items; and (3) journals with minimal impact, which comprise 246 items. Figure 7 represents the core zone of the sources according to Bradford's law, which published documents focusing on AI and ML in combating illegal financial operations.

Table 6 provides critical data for evaluating the local impact of journals. Notably, our sample's journal, «“IEEE Access»” (a multidisciplinary, all-electronic archival journal), got the highest level of all metrics, including the H-index, G-index, and M-index. Interestingly, IEEE Access does not get the most significant total citations (TC), relinquishing the leading position to the journal Expert Systems with Applications. The last one is also ahead of the Journal of Money Laundering Control (third H-index) and the ACM International Conference Proceeding Series (fourth H-index) by the indicator M-index. However, they have higher H-indexes and G-indexes.

Investigation of source activity over time shows that such publications as Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) began to publish individual articles on the topic with a focus on AI and ML in combating illegal financial operations as early as the 1990s. Still, most sources

began to publish articles much later in the 2020s actively. During this period, a rapid increase in publication activity on the analysed topic was observed in all the top 9 sources (Figure 8).

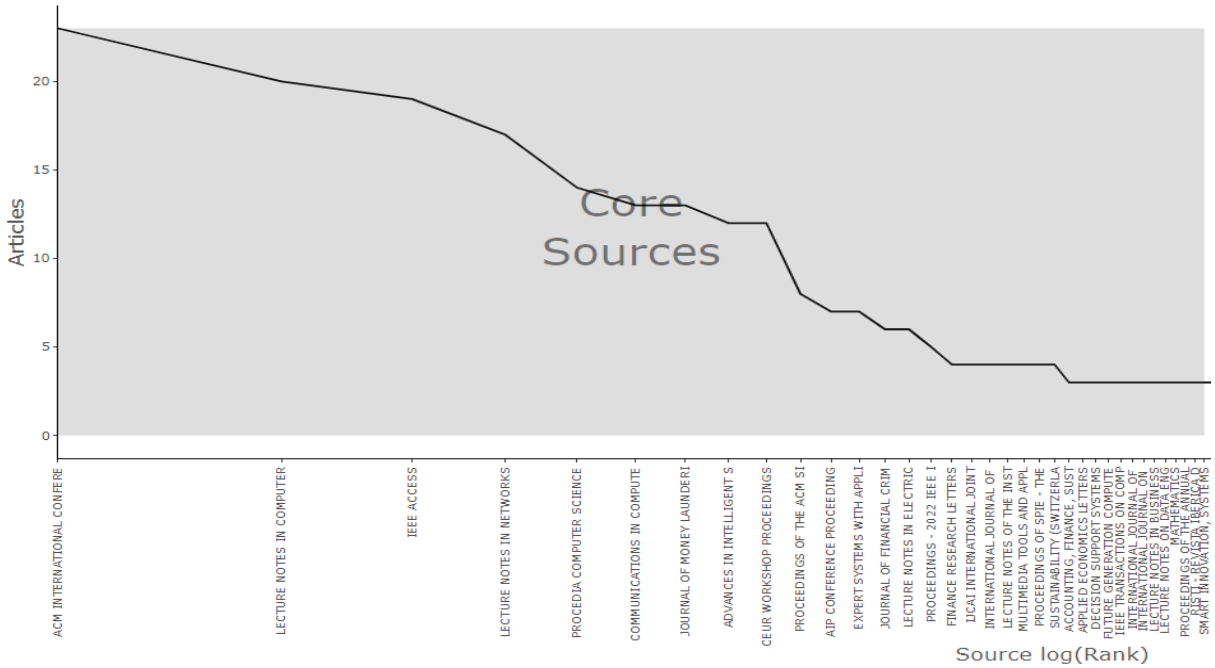


Figure 7. Core sources by Bradford's law
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

Table 6. Local impact of top 10 sources in the sample of the documents with a focus on AI and ML in combating illegal financial operations [Source: developed by the authors (based on the Scopus database using the Biblioshiny App).]

Element	H_Index	G_Inex	M_Index	TC	NP	PY_start
IEEE Access	10	17	1,429	298	19	2018
Procedia Computer Science	9	14	1	232	14	2016
Journal of Money Laundering Control	7	13	0,389	245	13	2007
ACM International Conference Proceeding Series	6	14	0,462	206	23	2012
Expert Systems with Applications	6	7	0,75	437	7	2017
Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	6	11	0,231	135	20	1999
Advances in Intelligent Systems and Computing	4	8	0,571	68	12	2018
Communications in Computer and Information Science	4	6	0,571	48	13	2018
Journal of Financial Crime	4	6	0,667	65	6	2019
CEUR Workshop Proceedings	3	6	0,375	44	12	2017

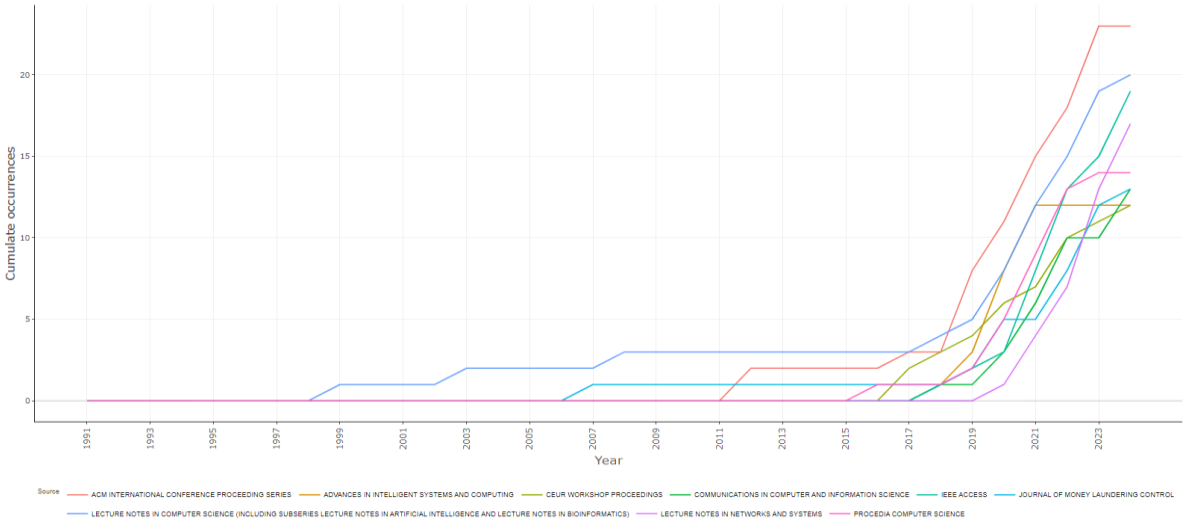


Figure 8. Top 9 sources' production over time.
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

Sankey plot based on the top sources, authors, and keywords (Figure 9) allows us to state that half of the top 20 sources published the authors' documents from the group's top 20. Most top authors published in Procedia Computer Science (5 from 20) (Figure 9). Also among the top 20 authors were the popular the ACM International Conference Proceeding Series (3 from 20 authors published in this source), the Journal of Money Laundering Control (3 from 20), the Proceedings of the ACM SIGKDD International Conference on Knowledge Discovery and Data Mining (3 from 20), etc. As for keywords, we cannot divide sources into specialisations according to keywords (Figure 9).

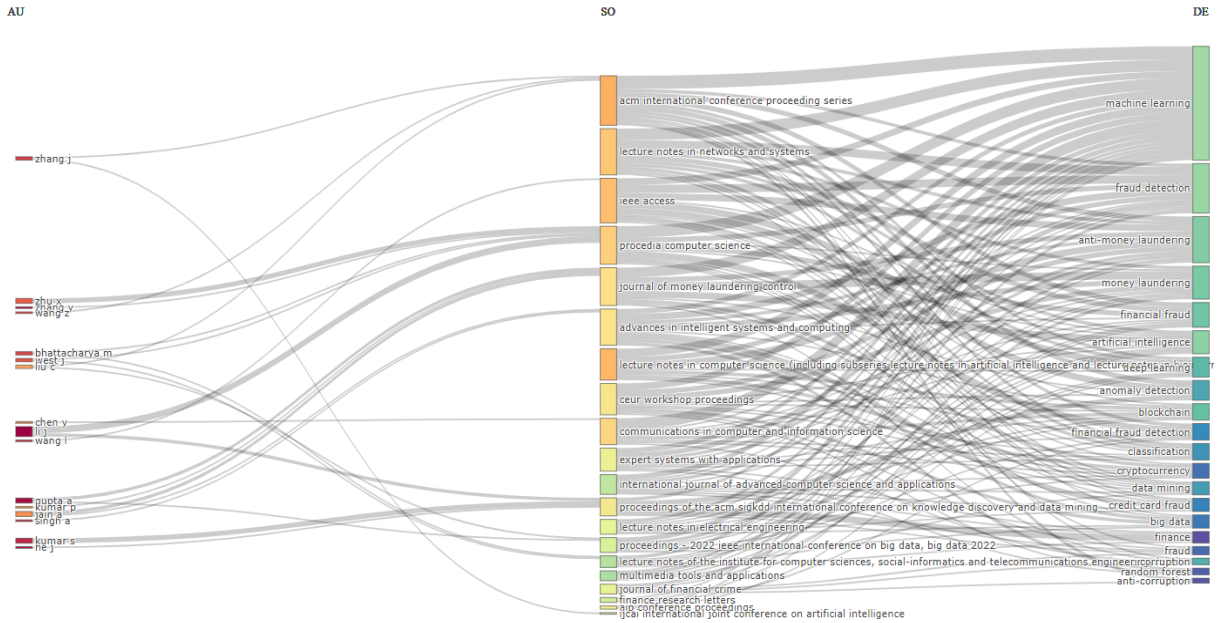


Figure 7. Three-field plot “Authors – Sources – Keywords» of publication with focus on AI and ML in combating illegal financial operations.
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

As can be observed in Figure 8, documents are characterised by low citation rates for almost the entire period. Only 2010 differs by meaningful indexes MeanTCperArt and MeanTCperYear owing to the paper by Bertot et al. (2010), which has 1591 citations and specifies such a significant variation of 2010 compared to other years. Also, it should be noted that Andersen (2009) and Shim & Eom (2009) (282 and 127 citations, respectively) provided the second indicator of average citations per article in 2009 (MeanTCperArt = 77.00). Publications by Awoyemi et al. (2017) and Hajek & Henriques (2017) (344 and 173 citations) provided a MeanTCperArt of 50.9 in 2017 despite the significantly higher number of articles published that year (Figure 8).

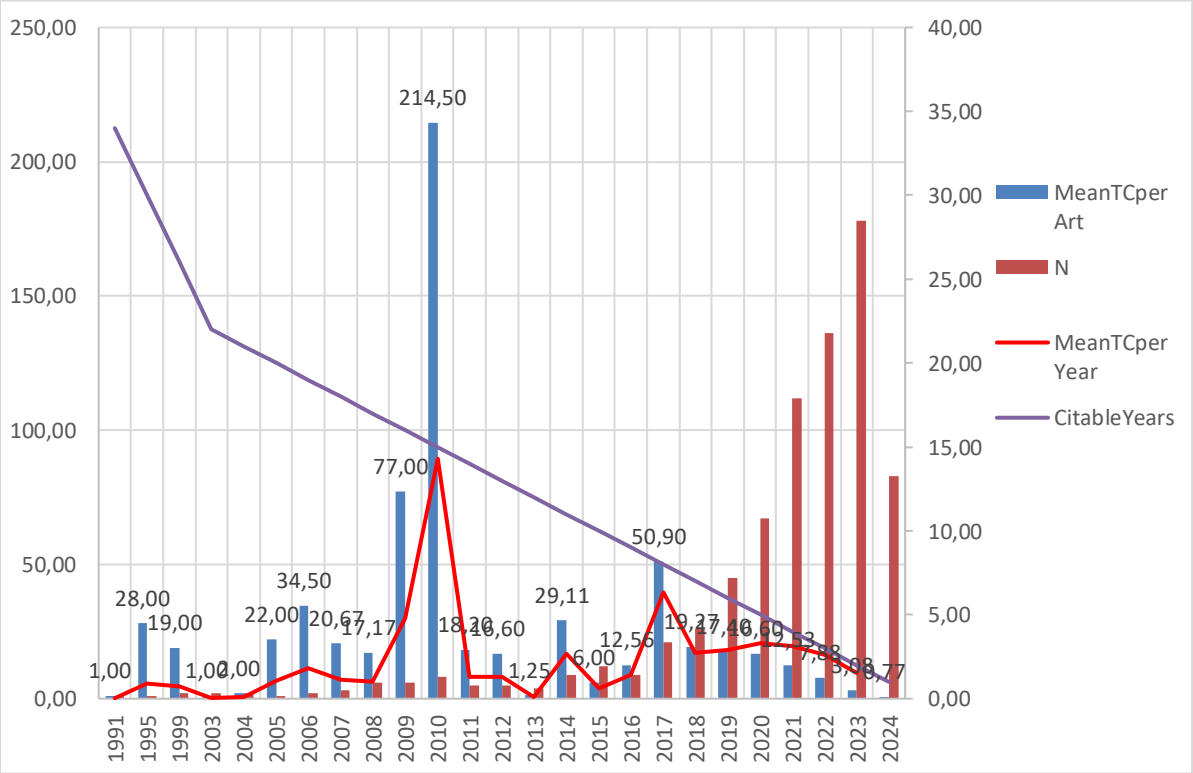


Figure 8. Average Citations Per Year of publications focusing on AI and ML in combating illegal financial operations.

[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

Citations in global measure indicate a document's influence across the bibliographic database, often attracting many citations from various research areas. In contrast, local citations count how frequently a paper was cited by other research within a particular investigated set (Biblioshiny Tutorial, n.d.). Tables 7 and 8 list the top 10 most globally and locally cited documents in our sample, respectively, along with their citation characteristics. The article by Bertot et al. (2010) is the most cited paper globally. This paper examined how information and communication technologies (ICTs), including e-government and social media, could be leveraged to promote transparency and combat corruption within societies, how they could facilitate greater openness in government operations, making information more accessible to the public and enabling citizens to hold their governments accountable. The authors highlighted

Tables 7. Most Global Cited Documents [Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

Paper	Author (s)	Source	Year	DOI	TC	TC p. Y.	NTC
We are using ICTs to create a culture of transparency: E-government and social media as openness and anti-corruption tools for societies.	Bertot, J. C., Jaeger, P. T., Grimes, J. M.	Government Information Quarterly, 27(3), 264–271.	2010	10.1016/j.giq. 2010.03.001	1591	106,07	7,42
Credit card fraud detection using machine learning techniques: A comparative analysis	Awoyemi J.O., Adetunmbi A.O., Oluwadare S.A.	2017 International Conference on Computing Networking and Informatics (ICCNI), Lagos, Nigeria, 2017, pp. 1-9	2017	10.1109/ICCNI. 2017.8123782	344	43,00	6,76
E-Government as an anti-corruption strategy.	Andersen, T. B.	Information Economics and Policy, 21(3), 201–210.	2009	10.1016/ j.infoecopol. 2008.11.003	282	17,63	3,66
E-Government, Internet Adoption, and Corruption: An Empirical Investigation	Elbahnasawy, N. G.	World Development, 57, 114–126	2014	10.1016/ j.worlddev. 2013.12.005	221	20,09	7,59
Mining corporate annual reports for intelligent detection of financial statement fraud – A comparative study of machine learning methods	Hajek, P., Henriques, R.	Knowledge-Based Systems, 128, 139–152	2017	10.1016 / j.knosys. 2017.05.001	173	21,63	3,40
Cross-domain analysis of ML and DL: Evaluating their impact in diverse domains.	Khetani V., Gandhi Y., Bhattacharya S., Ajani S.N., Limkar S.	International Journal of Intelligent Systems and Applications in Engineering, 11(7s), 253–262.	2023	https://ijisae.org/ index.php/ IJISAE/article/ view/2951	149	74,50	48,31
Detection of illicit accounts over the Ethereum blockchain	Farrugia, S., Ellul, J., Azzopardi, G.	Expert Systems with Applications, 150, 113318.	2020	10.1016/j.eswa. 2020.113318	144	28,80	8,68
Comparison and analysis of logistic regression, Naïve Bayes and KNN machine learning algorithms for credit card fraud detection	Itoo, F., Meenakshi, Singh, S.	International Journal of Information Technology, **13**, 1503–1511	2020	10.1007/ s41870-020-00430-y	132	33,00	10,54
Using social network analysis to prevent money laundering	Fronzetti Colladon, A., Remondi, E.	Expert Systems with Applications, 67, 49–58.	2017	10.1016/ j.eswa. 2016.09.029	129	16,13	2,53
Anti-corruption effects of information communication and technology (ICT) and social capital	Shim, D. C., Eom, T. H.	International Review of Administrative Sciences, 75(1), 99–116.	2009	10.1177/ 00208523 08099508	127	7,94	1,65

Note: **TC** – total citation**, TC p. Y.** – total citation per year**, NTC** – normalized total citation

Tables 8. Most Local Cited Documents [Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

Document	Author (s)	Source	DOI	Year	LC	GC	LC/GC Ratio (%)	NLC	NGC
Detecting money laundering transactions with machine learning	Jullum, M., Løland, A., Huseby, R. B., Ånonsen, G., Lorentzen, J.	*Journal of Money Laundering Control*, *23*(1), 173–186.	10.1108/ JMLC-07-2019-0055	2020	28	75	37,33	19,54	4,52
Using ICTs to create a culture of transparency: E-government and social media as openness and anti-corruption tools for societies	Bertot, J. C., Jaeger, P. T., Grimes, J. M.	*Government Information Quarterly*, *27*(3), 264–271.	10.1016/ j.giq. 2010.03.001	2010	17	1591	1,07	5,67	7,42
Leveraging machine learning in the global fight against money laundering and terrorism financing: An affordances perspective	Canhoto, A. I.	*Journal of Business Research,* 131, 441-452	10.1016/ j.jbusres. 2020.10.012	2021	16	73	21,92	21,08	5,83
Machine Learning and Sampling Scheme: An Empirical Study of Money Laundering Detection	Zhang, Y., Trubey, P.	*Computational Economics*, *54*(3), 1043–1063.	10.1007/ s10614-018-9864-z	2019	16	49	32,65	14,69	2,82
Credit card fraud detection using machine learning techniques: A comparative analysis	Awoyemi J.O., Adetunmbi A.O., Oluwadare S.A.	*2017 International Conference on Computing Networking and Informatics (ICCNI)*, Lagos, Nigeria, 2017, pp. 1-9	10.1109/ ICCNI. 2017.8123782	2017	16	344	4,65	7,30	6,76
Investigation of Applying Machine Learning for Watch-List Filtering in Anti-Money Laundering	Alkhalili, M., Qutqut, M. H., Almasalha, F.	*IEEE Access*, *9*, 18481–18496.	10.1109/ ACCESS. 2021.3052313	2021	15	35	42,86	19,76	2,79
Mining corporate annual reports for intelligent detection of financial statement fraud – A comparative study of machine learning methods	Hajek, P., Henriques, R.	*Knowledge-Based Systems*, *128*, 139–152.	10.1016/ j.knosys. 2017.05.001	2017	13	173	7,51	5,93	3,40
Competence of Graph Convolutional Networks for Anti-Money Laundering in Bitcoin Blockchain. In	Alarab I., Prakoonwit S., Ikbal Nacer M.	Proceedings of the 2020 5th International Conference on Machine Learning Technologies (ICMLT '20), 23–27.	10.1145/ 3409073. 3409080	2020	12	65	18,46	8,38	3,92
Comparative Analysis Using Supervised Learning Methods for Anti-Money Laundering in Bitcoin.	Alarab I., Prakoonwit S., Ikbal Nacer M.	Proceedings of the 2020 5th ICMLT '20, 11–17.	10.1145/ 3409073. 3409078	2020	12	46	26,09	8,38	2,77
Performance of machine learning techniques in the detection of financial fraud	Sadgali, I., Sael, N., Benabbou, F.	*Procedia Computer Science*, *148*, 45–54.	10.1016/ j.procs. 2019.01.007	2019	11	77	14,29	10,10	4,43

Note: **Y.** – year of publication, **LC** – local citations**, GC** – global citations**, NLC** – normalised local citations, **NGC** – normalised global citations

the importance of e-government initiatives, which use digital tools to streamline government processes, enhance service delivery, and provide transparent access to government information. Social media platforms were discussed as powerful tools for fostering dialogue between governments and citizens, encouraging public participation, and disseminating information widely and quickly. The authors argued that ICTs could effectively reduce corruption by increasing the visibility of government activities, providing mechanisms for reporting and tracking corruption, and fostering a culture of accountability. The article also addressed the challenges associated with implementing ICT-based transparency initiatives, such as the digital divide, privacy concerns, and the need for effective policies and regulations.

The second in this rank is the paper by Awoyemi et al. (2017), which evaluated the performance of three techniques – naïve Bayes, k-nearest neighbour, and logistic regression – on credit card fraud dataset (284,807 transactions from European cardholders). A mixed approach of under-sampling and over-sampling was applied to the compromised data to address the data imbalance. These techniques were tested on raw and pre-processed data, and the implementation was done in Python. The results indicated optimal accuracy rates of 97.92% for naïve Bayes, 97.69% for k-NN, and 54.86% for logistic regression. Comparative results revealed that the k-nearest neighbour beats both naïve Bayes and logistic regression.

Interestingly, the article by Bertot et al. (2010) ranks second in the ranking of the most locally cited documents. The most locally cited document is the article by Jullum et al. (2020), which explored the application of machine learning techniques to identify money laundering activities. The authors discussed developing and implementing machine learning simulations designed to detect suspicious financial transactions that may indicate money laundering. They analysed the effectiveness of these models using real transaction data, highlighting their potential to improve the detection of illicit financial activities. The study emphasised the importance of advanced data analysis and machine learning in developing the capabilities of financial institutions and regulatory bodies to combat money laundering.

Words that frequently co-occur within a document and form a connection within a network are commonly called a co-words network. Found network construction helps discover the themes within an investigating topic, identifying key and emerging subtopics, referred to as the research border. It also assists in monitoring the progression of issues over time (Biblioshiny Tutorial, n.d.).

According to Table 1, Keywords (Author) have only 12.60 losses and have been acceptable for analysis. The unifying theme of the keywords of the most significant red cluster (including 20 keywords, Figure 9) is the application of advanced computational techniques and algorithms, particularly in artificial intelligence and machine learning, to identify and avoid fraudulent operations across various financial and cybersecurity contexts. These keywords reflect the interdisciplinary approaches to improve the accuracy, efficiency, and transparency of identifying and mitigating fraud in digital and financial environments.

The authors' keywords of the green cluster are dedicated to using artificial intelligence and machine learning to identify, prevent, and manage financial crimes such as money laundering and fraud. These keywords reflect the integration of sophisticated data analysis and algorithmic techniques within the finance and banking sectors to enhance transaction monitoring, ensure regulatory compliance, and combat financial crime (Figure 9). The connecting theme of the keywords of the yellow cluster (blockchain, cryptocurrency, bitcoin, cybercrime, fintech, security, Ethereum – Figure 9) is the intersection of advanced digital financial technologies

and cybersecurity. These terms are all related to the use and impact of blockchain technology and cryptocurrencies in the financial technology (fintech) industry, highlighting concerns about security and the potential for cybercrime within these emerging financial systems. The blue cluster (Figure 9) is connected to applying advanced analytical and computational techniques to detect and avoid fraudulent activities in financial transactions, particularly credit card fraud. These terms emphasise using data mining and computational intelligence methods to improve the accuracy and increase the efficiency of fraud detection systems through effective feature selection and analysis.

The unifying theme of the keywords of the violet cluster is the employment of digital technologies and platforms to promote transparency and combat corruption. These terms highlight how information and communication technologies (ICT) and social media can be leveraged to increase accountability, provide greater access to information, and foster public engagement to reduce corruption. Keywords corruption and technology occupied two separate clusters (purpure and brown).

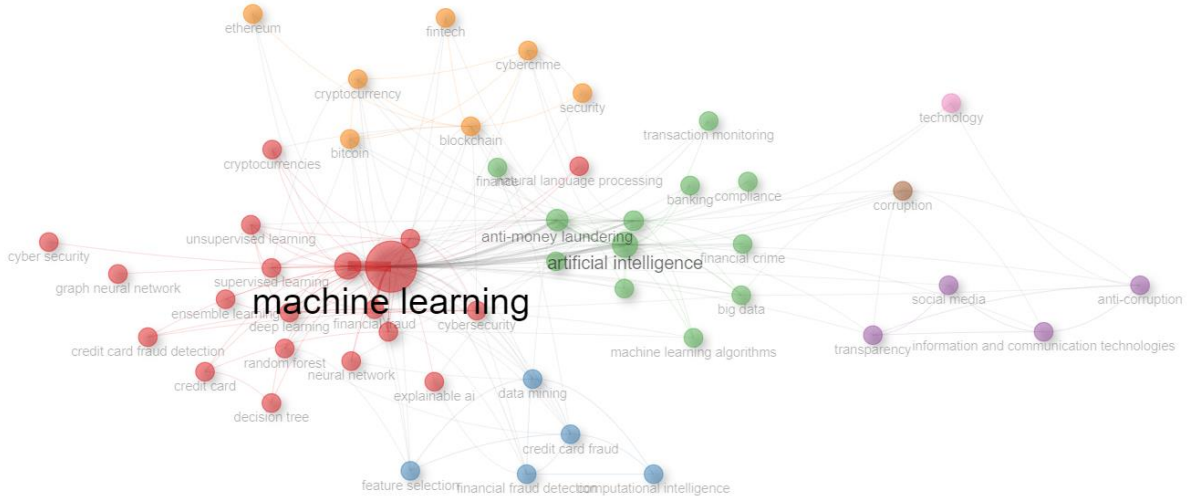


Figure 9. Co-occurrence author's keywords network.
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

As for keywords plus, the construction of the co-occurrence network identifies only two clusters:

1. The subtopics of the red cluster collectively emphasise the integration of machine learning and advanced data analysis techniques in combating financial crime and improving the security and integrity of financial systems. They also could be divided into subgroups: (1) the use of machine learning, deep learning, neural networks, support vector machines, decision trees, random forests, and nearest neighbour search in building predictive models for fraud detection; (2) techniques specifically targeting the detection and prevention of financial fraud, including credit card fraud and fraudulent transactions in commerce and investment; (3) employing data mining and feature extraction methods to analyse large datasets for identifying patterns and anomalies indicative of fraud; (4) protecting financial transactions and systems from cybercrime and ensuring network security to prevent unauthorised access and fraud; (5) leveraging ICT to enhance fraud detection systems and

improve decision-making processes related to financial crime prevention; (6) applying machine learning in financial sectors to safeguard investments, forecast risks, and minimise losses due to fraudulent activities; (7) using e-learning platforms and managing large datasets to train and refine fraud detection models and systems.

2. The keywords of the red cluster are centred around the integration of AI, machine learning, blockchain, and big data analytics in enhancing the detection and prevention of money laundering within financial systems. This cluster also includes some subthemes:
    - Utilising AI, supervised learning, anomaly detection, convolutional neural networks, and graph neural networks to develop models for identifying suspicious activities and patterns indicative of money laundering.
    - Employing blockchain technology and cryptocurrencies such as bitcoin to understand and mitigate money laundering risks in decentralised financial systems.
    - Implementing AML measures and practices to prevent and detect money laundering activities within financial institutions.
    - Leveraging big data analytics to process and analyse large financial transaction volumes to identify unusual behaviour and potential laundering activities.
    - Conducting risk assessments and monitoring financial institutions to ensure compliance with AML regulations and effectively manage financial transaction risks.
    - Addressing challenges and developing solutions for detecting laundering activities involving electronic money and digital currencies.

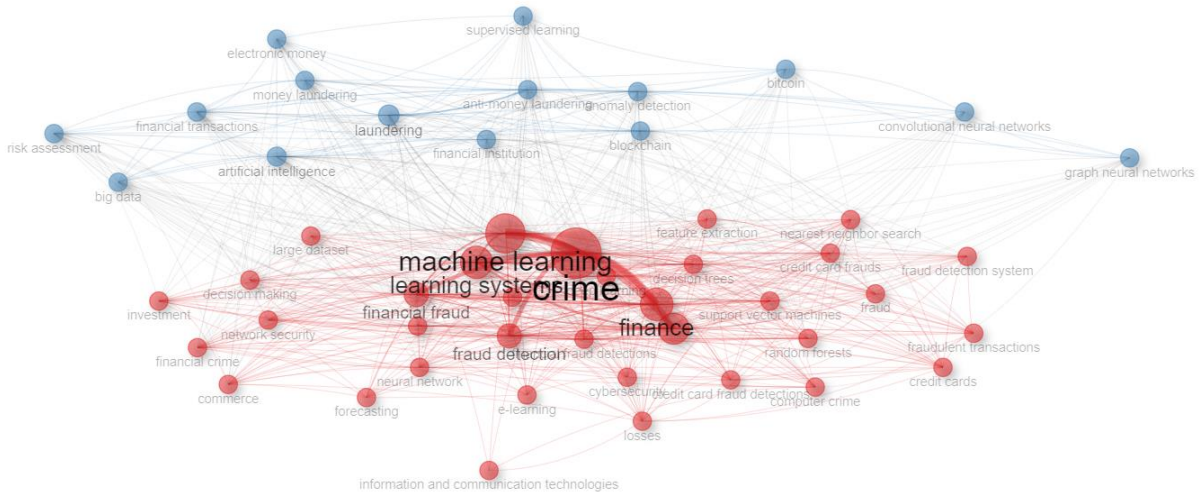


Figure 9. Co-occurrence keywords plus network.
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

Figure 10 presents the different keywords from the list of Titles and abstracts.

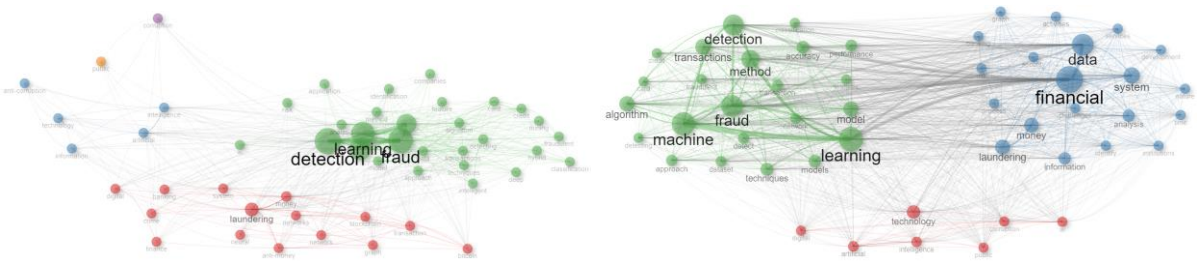


Figure 10. Co-occurrence keywords from the list of Titles and Abstract network.
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

Notably, keywords from numerous clusters and investigating sub-themes are intently joined, reflecting a trend toward merging in academic research. The Biblioshiny app helps identify the most relevant and progressed paper types and track their movements over time by assessing their growing relevance and development levels. An alluvial diagram in Figure 12 visualises the evolution of themes in the scholarly literature on AI and ML in combating illegal financial operations. Like a flowchart, this diagram successfully demonstrates the change and revolution of themes within the investigating sample over time (Aria & Cuccurullo, 2017). Longitudinal analyses of documents stress topics' joining, convergence, or deviation over time (Aria & Cuccurullo, 2020).

The moment was chosen by the detected bifurcation points of the trend change in the number of publications presented in Figure 1. These are the years 2003 and 2015. The few publications of the early period of 1991-2003 are mainly devoted to applying artificial intelligence in combating illegal financial operations. Interestingly, they were transformed into the Crime sub-topic in the following period of 2004-2015. From 2004 to 2015, new sub-topics appeared: ICT, decision-making, computer crime, government data processing, and data security (Figure 11).

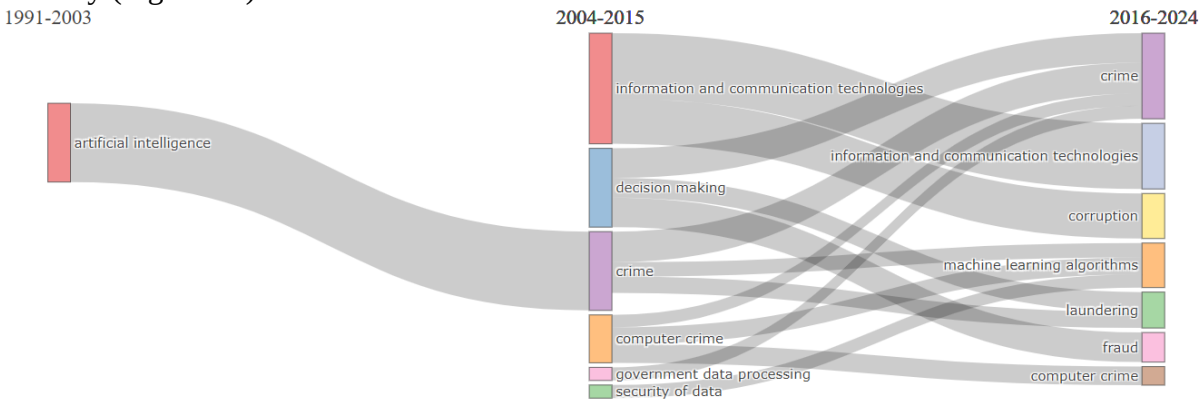


Figure 11. A Longitudinal Thematic Map Analysis in a sample of publications with a focus on AI and ML in combating illegal financial operations
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

However, these subtopics will transform in the next period. A group of studies focused on corruption research stood out from the sub-topic of ICT. Studies with the keywords machine learning algorithms and laundering stood out from the crime subtopic. Subtheme Decision-making was separated into subtopics, such as fraud, and it partially joined the subtopics of laundering and crime. Part of the research in the subtopics of Computer crime also migrated to

the subtopics of Crime and Machine learning algorithms. The last-mentioned sub-topic also included research from 2004-2015 with a sub-topic like the security of data, which means that more and more studies are investigating the use of machine learning in cybersecurity, detecting suspicious operations and criminal crimes, including cybercrime (Figure 11).

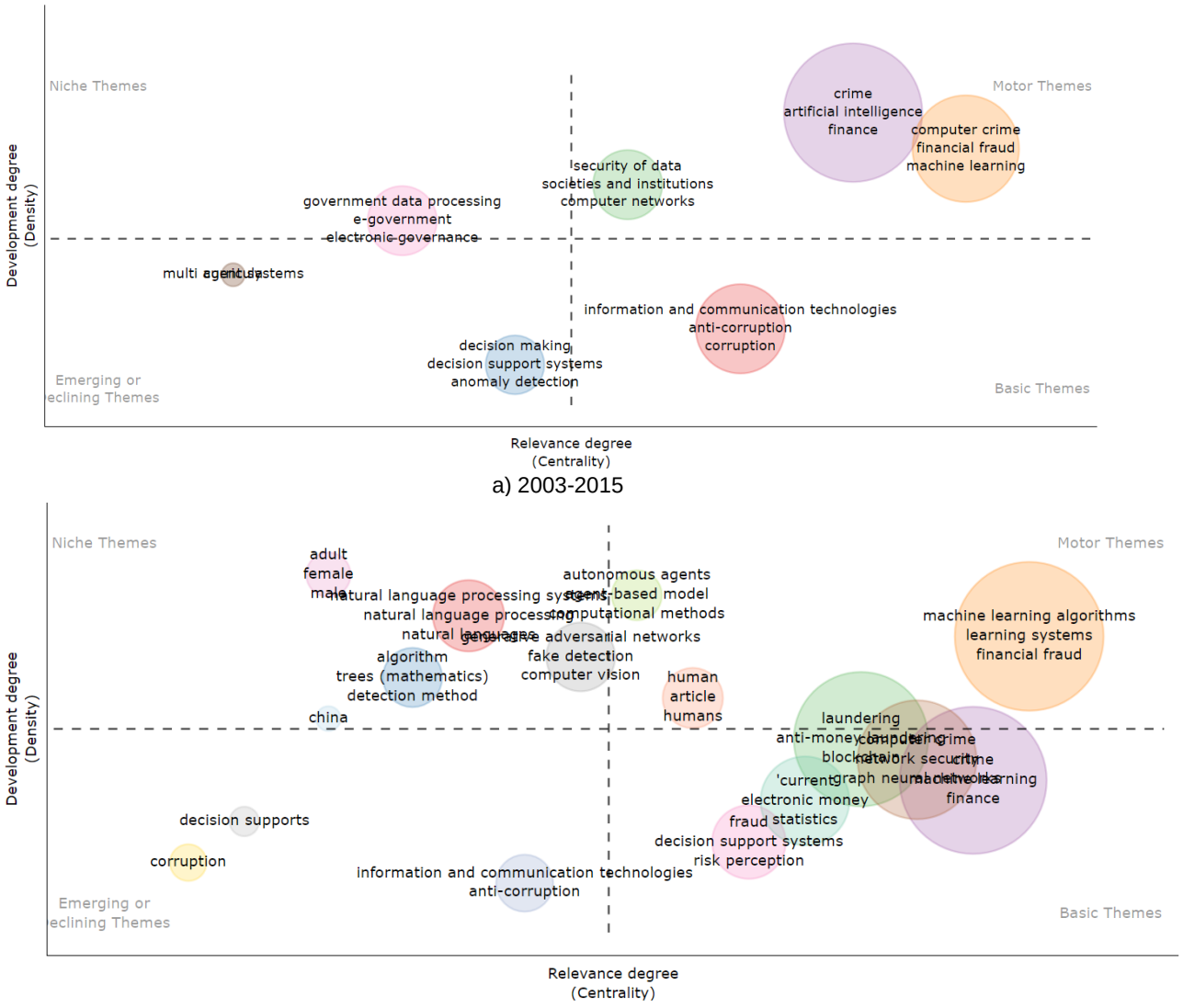


Figure 12. Mapping of relevance degree and development degree of subtopic in documents with a focus on AI and ML in combating illegal financial operations

[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

The bibliophile clustering algorithm for the keywords' network enables the identification of different themes within a sample of publications. Each theme or cluster can be depicted on a specific plot called a Thematic map (Cobo et al., 2011). Centrality measures the relevance of a theme, while density measures its level of development. This framework allows us to categorise themes into the following quadrants:

- Highly developed and isolated themes (Niche).

- Emerging or declining themes.
- Motor themes.
- Basic and transversal themes.

In our case, it is interesting to investigate the location of subtopics in the «Degrees of compliance-development» matrix in the time frames of 2003-2015 and 2016-2024. The results are presented in Figure 12. The main topics in 2003-2015 included ICT, anti-corruption, and corruption. Special topics were state data processing, e-government, and e-governance. It should be noted that the ICT, anti-corruption, and corruption sub-topics have moved in 2016-2024 into the quadrant of declining topics. Such subtopics as Machine learning algorithms, Learning systems, and Financial fraud are Motor themes. The location of other subtopics in the «Degrees of compliance-development» matrix is presented in Figure 12 a, b.

The closeness between keywords indicates shared content: keywords are tight to each other because a significant ratio of articles discusses them; they are situated at a distance when only an insignificant segment of articles uses these keywords. The basis of the map characterises the mean location of all column profiles, thus marking the centre of the investigated sample, which indicates common and widely split topics (Cuccurullo et al., 2016). Clusters are identified through hierarchical clustering (Figure 13). Fractals of keywords are grouped around separate subtopics: (1) Machine learning and its application in determining fraudulent transactions; (2) the use of big data and data mining in the determination of financial fraud in the financial and commercial spheres; (3) credit card fraud detection; (4) AI in the detection of financial and computer crimes; (5) use of neural networks and blockchain technologies in the detection of abnormal activity; (6) AML; (7) using nearest neighbour search and random forest methods; and (8) Bitcoin.

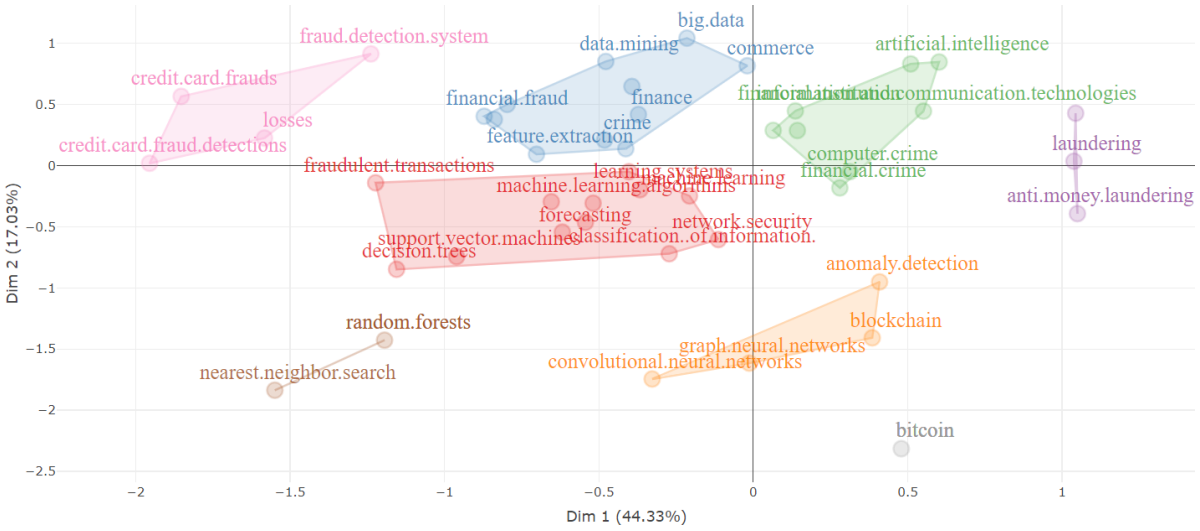


Figure 12. Multiple correspondence analysis.
[Source: developed by the authors (based on the Scopus database using the Biblioshiny App)]

CONCLUSIONS

The relevance of Artificial Intelligence (AI) and Machine Learning (ML) in combating illegal financial activities is increasingly evident in today's financial and technological landscape. Implementing advanced AI and ML systems demonstrates a solid commitment to security and transparency, which can enhance customer confidence and strengthen the institution's reputation. As financial crimes become more sophisticated and regulatory pressures increase, the role of AI and ML in ensuring financial security is more critical than ever. These technologies provide sophisticated, efficient, and practical solutions for detecting and preventing financial crimes, making them indispensable tools for financial institutions worldwide. A comprehensive and inclusive bibliometric analysis can shed light on the state of the art and possible future vectors of AI and ML applications in this field, equipping researchers and practitioners to report the complex challenges financial crimes pose in a rapidly evolving digital environment.

The analysis covers publications from 1991 to the first half of 2024, involving 2103 unique authors, including 85 who authored single-author documents. The average number of co-authors per document is 3.31, and 49.06% are conference papers. There has been a steady growth in publications, with an annual growth rate of 14.33%. Notably, a significant number of these publications are recent, with an average document age of 3.51 years.

From 1991 to 2002, publications on AI and ML in combating illegal financial operations appeared sporadically, marking the initial interest in the field. The period from 2003 to 2015 saw a rise in publication activity, with a trend resembling exponential growth. The period from 2015 to 2024 experienced rapid growth, explained by a polynomial trend of the second degree. These findings affirm the growing research interest in this area, especially from 2003 onwards.

The most cited publication in this domain is by Randhawa et al. (2018), which explores the use of machine learning algorithms for credit card fraud detection. Jingyu Li, a researcher from the Beijing Institute of Technology, emerged as the most productive author, contributing significantly to the literature. According to Lotka's law, as the number of publications rises, the frequency of authors contributing to many documents decreases, with only one author (Li J.) publishing ten articles. In contrast, most authors have published only one article.

International collaboration is evident, with 18.23% of publications involving co-authorship across countries. This shows strong international cooperation in the research field, with Canada, Bangladesh, and Brazil primarily publishing single-country papers. The United Arab Emirates exhibits the highest MCP ratio. China leads in the number of publications, followed by India, the USA, the United Kingdom, and Italy, collectively accounting for 32.7% of the publications.

According to Bradford's law, journals are divided into three categories: core journals (35 items), significant contributors (196 items), and less influential journals (246 items). Key sources, such as Lecture Notes in Computer Science, began publishing relevant articles in the 1990s, with a noticeable increase in publications from the 2020s.

Citation rates are generally low, with a notable spike in 2010 due to the highly cited work by Bertot et al. (2010). The primary cluster of keywords focuses on using advanced computational techniques, particularly AI and ML, to detect and prevent fraud in various financial and cybersecurity contexts.

The analysis segmented the timeline into distinct periods based on publication trends: 1991-2003 (early AI applications in combating illegal financial operations), 2004-2015 (emergence of new subtopics like ICT, decision-making, computer crime, government data processing, and data security), and 2016-2024 (expansion into big data, neural networks, blockchain technologies, and AML). Key subtopics include machine learning for fraud detection, big data and data mining for financial fraud, credit card fraud detection, AI in financial and computer crime detection, and neural networks and blockchain technologies.

While this study offers valuable scholarly insights, it has several limitations. Relying solely on the Scopus database may have led to the exclusion of other relevant studies. Additionally, the review was limited to journal articles, books, chapters, and conference papers, leaving out other potential sources of knowledge. Furthermore, the findings were based on the authors' specific set of keywords, highlighting the need for validation through empirical methods like expert interviews and surveys.

IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

Integrating artificial intelligence (AI) and machine learning (ML) in combating illegal financial activities offers significant advancements in detection and prevention, which are essential for both research and policy development. Research implications include the need for further exploration of ethical concerns, privacy, and bias in AI/ML applications and the development of more sophisticated algorithms. Application-wise, financial institutions should adopt AI/ML technologies to enhance compliance with anti-money laundering regulations and reduce operational costs through automated fraud detection. Policymakers must address the regulatory challenges posed by the cross-border nature of financial crimes and promote international collaboration to utilise AI/ML tools effectively.

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WHO SETS THE PACE IN ROBOTISATION? 'WORKING AT A ROBOTIC PACE' ACCORDING TO THE JUSTIFYING, CRITICISING AND PROBLEM-SOLVING DISCOURSE FRAMES

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Abstract: *In a society driven by clock time and technology, it is no suprise that a robotic working pace is often viewed as inevitable, even ideal. However, ultimately discussions regarding robotic pace are shaped by different perspectives and contexts. In this paper, content-frame analysis was used to examine how 'working at a robotic pace' is addressed in academic discourse across scientific disciplines. The statements (N=22) were coded and examined for their positive, negative, or neutral appraisal, as well as the value base derived from either a human(e) or efficiency perspective. In academic communication, the concept has been framed by justifying, criticizing, and problem-solving discourses. The criticising frame was not found exclusively in the social sciences but across disciplines. It was the most common discourse frame, with its subjective perspective focusing on people and well-being. The problem-solving frame included a neutral, constructive and more objective approach associated with socio-technical ideals emphasized in engineering disciplines.*

Keywords: *frame analysis, robots, sociology of scientific knowledge, sociology of technology, values, working life.*

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INTRODUCTION

This study examines how the concept of 'working at a robotic pace' is portrayed in published academic works. This paper was inspired by the debate as to whether machinery, or rather clock time, is the root of industrialisation. If the clocks run our thoughts and actions, are the ideals of efficiency and expeditiousness presumed as axiomatic also prevalent in situations where people are expected to work at the speed of a robot?

The development of the steam engine in the 1800s is usually considered the starting point of the Industrial Revolution, which was followed by robotisation in the 1900s. However, challenging the idea of steam engines being the primary driver of the first major technological change in the world, Lewis Mumford (2010: 134) argued that the invention of the mechanical clock was actually the key to industrialisation. Although sometimes playful in his speculations, Mumford is primarily known as a sharp critic of rapid technological changes and he saw the idea of a mechanical society run by timetables as a red flag (Loeb, 2021). Mumford (2010: 269) criticised the clock-bound routine for its unnatural precision; for example, instead of waking up naturally, our sleep is curtailed by an alarm clock. Starting the day by the clock is only the first taste as to how the day will proceed in a predefined schedule of regular functions, limited durations and, just generally, keeping a keen eye on the time.

The clock has not lost its mastery of our lives in contemporary work culture. Digitalisation and new-generation robotisation have brought more recent technological changes to society and working life. Either as a separate development or in association with novel technologies, work is now more intense and time conscious than before (Aneesh, 2001; Mauno, Kubicek, Feldt, & Minkkinen, 2020). Robotisation has evident parallels with clock time dependence. Robots created for assembly work set the pace of work because, first, of the schedules and workflow that are planned in a robot-centred way and, second, how the work requires the people to keep a keen eye on the robotic pace.

Intense and hectic work can theoretically increase or decrease job satisfaction (Mauno et al., 2020; Sobczak, 2022), but how is this duality applicable in the demands of higher effectiveness associated with a robotic pace of work? How has this need for robotic speed been framed in academic discussions? This study investigates how working at a robotic pace is framed in academic communications, by which this study refers to the writings of scholars and students from any discipline (Park, 2008)[1]. In doing so, this study acknowledges that the academic discourse on technology typically varies among disciplines. Working at a robotic pace is a theme that regularly comes up in everyday discussions[2-3] - , but the question is, how has this idea been addressed in academic discussions occurring in various scientific communities?

The first research question of this content–frame analysis asks what the prevalence and content (Matthes & Kohring, 2008) of robotic pace discourse is. The second question is, how has the discourse on robotic pace framed the issue, whether that be positive, negative or neutral, and do such appraisals underlie human(e)- or efficiency-based values? Furthermore, from the framework of the sociology of knowledge, this work examines how scientific backgrounds, from the natural sciences to humanities, contribute to different perspectives on technology (Petrović, 2022; Östlund, 2004).

SOCIOLOGY OF SCIENTIFIC KNOWLEDGE IN ROBOTISING WORK

The sociology of scientific knowledge, as the communication-focused domain of science and technology studies, analyses here the way academic discussions are socially shaped or constructed (Park, 2008). According to this framework, structures can be found from various perspectives in academic discourse. Applied to the method of content–frame analysis, the structures are organised as found differences in the framing of a concept in question (Petrović, 2022). Thus, this study expects to find varied interpretations of the concept of 'working at a robotic pace' depending on the scientific discipline (Winskel & Radcliffe, 2014).

The premise here is the variance in perspectives among disciplines—more specifically, the difference between engineering and humanistic sciences—disciplines that both have a significant history in studying technology and technologising society. The engineering sciences have a tradition of using mathematics and physics to develop practical solutions. However, the humanities relies on interpretation and critical thinking in its objective of exploring human culture, thought and expression. These differences go beyond the methodologies used or the research questions set according to discipline. The engineering and humanistic disciplines differ in their understanding of the nature of knowledge. Technical research is set on applying analytical knowledge that is usually independent of context, whereas in the social sciences, epistemological interests lie more in ethical, behaviour-oriented and context-dependent issues (Östlund, 2004). In discourse ethics, pragmatic discourses of rational deliberation about means and ends are separated from moral discourses valuing justice and universalism (Habermas, 1997).

These epistemological differences have been concretised in studies of robotisation. New-generation robotics has resulted from advances in both artificial intelligence (AI) and sensor technology research. Developments in machine learning and more precise sensors for navigation and detection have made it possible for robots to work safely among people and to be mobile in their environment instead of being in fixed stations. Given these advances in technological development, the 'only' question is, how much can productivity increase following robotisation so that such developments are worth the investment? Robots' cost-effectiveness in given tasks and processes is calculated and estimated by the engineering sciences. This field of research concentrates on the instrumental rationality of robotising production, or other processes of work, to make them more efficient. From this perspective, it makes little difference whether the topic is robotising the industrial assembly line (Khan, Homri, Dantan, & Siadat, 2022) or healthcare (Huter et al., 2020).

The bracketing of 'only' in quotation marks in the previous paragraph was done to imply how, in reality, the social sciences also deliberate when robotising work is appropriate and justified. Aside from the availability of technology and the mechanistic rationality supporting it, human and social factors are also factors to consider when planning to introduce robots into a social environment. Although some human factors, such as security issues and user experiences, have been included in robotics studies (Ng, Chen, Lee, Jiao, & Yang, 2021), ethical issues have remained the purview of the social sciences and humanities (Östlund, 2004). Ethical issues associated with robotisation can be understood as work ethics and AI ethics. Working with robots raises ethical issues such as maintaining a sense of control in one's work, feeling safe while working and being threatened by technological unemployment (Deranty & Corbin, 2022; Melkas, Hennala, Pekkarinen, & Kyrki, 2020). AI ethics, then, include a range of ethical dilemmas, from normative issues to complex social relationships and the division of power (Lin,

Abney, & Bekey, 2011; Zhu, Liu, Huang, & Guo, 2023). Ethical issues are at the heart of robot studies in the social sciences and humanities, and this too can apply to several contexts, from robotising the industrial assembly line (Braun, Tigard, Schönweitz, Lucaj, & von Janowski, 2022) to healthcare robotics (Turja & Parviainen, 2020).

In reorganising work after a technological shift, reskilling the staff is a topic that lands in between the values of cost efficiency and human factors. On the one hand, from a deterministic view, reskilling after robotising work embraces innovations, and the staff is expected to acquire new skills to adopt all novel technology (Sony, Antony, & Tortorella., 2023). On the other hand, reskilling is viewed as a means to support workers' job satisfaction, as reskilling can free them from routines and offer more gratifying tasks (Dølvik & Steen 2018; Sobczak, 2022). Contrary to reskilling, deskilling refers to a negative trajectory in which job descriptions are changed to take on a more modest and repetitive direction (Harju, Hakanen, & Schaufeli, 2014; Weinberg, 2016). In the rationality of clock time, efficiency and standardised work processes, robotising work comes with the risk of deskilling both job descriptions and entire professions (Turja, Särkikoski, Koistinen, Krutova, & Melin, 2022a).

The hypothesis is that the robotic pace is a continuum and an accelerator of the clock-centred culture. Under this assumption, working at a robotic pace is viewed as an ideal that reflects both positively (efficiency) and negatively (human factors) on working life.

However distinct from each other, the traditions of the engineering sciences and humanities can also be aligned, as shown in the sociology of technology. Interactions between technologisation and societies are studied in the sociology of technology and socio-technical systems. In an idealistic socio-technical system, research plans should always acknowledge both the technical and social domains (Trist, 1981). The socio-technical perspective originated from and has been widely accepted in attempts to find symbiosis between technological changes and well-being at work. Furthermore, the collaboration between humans and robots can even reach the ideal workflow when work and roles between these two quite different actors are optimised (Militello et al., 2013). In addition to the optimal workflow, ethical values play an important role in socio-technical systems. Pekkarinen et al. (2020) provided an interesting example of this, in which care robots can be accepted by staff only when they prove to be both useful and in line with the ethical values of care work.

Regardless of the theoretical ideal of socio-technical principles guiding studies on robotising work, it is still hypothesised – based on the premise that an ethical consensus can exist only within a single community (Habermas, 1997; Keulartz, Schermer, Korthals, & Swierstra, 2004) – that human factors, and ethical values in particular, are valued more commonly in social studies than in engineering studies. In a similar vein, this study presumes that working at a robotic pace receives more positive appraisals in the discourses found in the engineering sciences compared to discourses found in the social sciences.

METHODS

This qualitative study used content–frame analysis to identify meanings and describe discourses associated with 'working at a robotic pace'. The purpose of content analysis is to describe the characteristics of linguistic content by examining the source, the target audience and the intention of the discourse (Vaismoradi, Turunen, & Bondas, 2013). Content analysis

is used to produce a collective understanding or parallel understandings of a phenomenon (Pfeil & Zaphiris, 2010).

In the more specific content–frame analysis, the themes derived from the analysed content are further identified as comprised and dominant frames (Tankard, 2001). Frame analysis originated from Erving Goffman's (1974) methodology for understanding and naming meanings by analysing the relationship between concepts and text. In the current study's design, frames represent the beliefs and purposes through which working at a robotic pace is interpreted (see Bergenheim, 2020). Frames define perspectives, and aside from the defining work, frame analysis can be used to examine the strength of the various forces creating these perspectives (Entman, 1993).

The data consisted of all English-language mentions of working at a robotic pace found in academic writings. The search was conducted using the Wiley Online Library, a multidisciplinary database, and complemented by Google Scholar, which provided an even wider scope that included also informal commentary pieces (see Park, 2008). The Wiley Online Library provides consistent search results independent of the institution possessing the licence for a work, unlike larger databases, such as ProQuest and Web of Science (Gusenbauer & Haddaway, 2020).

The search terms used were 'work' and various versions of the phrase 'robot/robotic pace'. The search was conducted in August 2023. After removing duplicates and irrelevant search results (e.g. pace referring to a robot's gait), the data consisted of 22 statements as the observatory units, given this study's design.

In exploring the use of the phrase 'working at a robotic pace' as a linguistic unit and as a social phenomenon, the statements mentioning robotic pace in a work-related context were themed according to their positive, negative or neutral nature as well as the value base and primary reason informing the stated position (Park, 2008). The value base was derived from the perspectives of efficiency or human factors. If both value bases were present in the statement, both were coded to be associated with the one statement.

In the first phase of content analysis, some of the neutrality codings had another parallel coding of either positive or negative appraisal associated with them. These placed consistently so that the value of efficiency correlated with neutral-positive appraisals and the value of human factors correlated with neutral-negative appraisals. In the next phase of the analysis, these double codings were dismantled, leaving the neutral category pure and without nuances of parallel positive or negative views. The statements were also categorised by their publication year, scientific discipline and the context of the robotising discourse for finding further intersections and discrepancies among the frames. The scientific discipline was determined by the first author of the document. The studies behind the statements were dominantly mono-disciplinary, as is common (Van Leeuwen & Tijssen, 2000). See Table 1 for the distribution of statements. Detailed descriptions with the original quotes can be found in Appendix A.

Table 1. Statement distributions (N = 22) for 'working at a robotic pace'

	n
Publication year	
1988–1999	4
2012–2019	5
2020–2023	13
Appraisal of 'working at a robotic pace'	
Positive	4
Negative	11
Neutral	7
Context	
Industrial manufacturing	14
Construction sites	2
Warehouse work	1
Medical surgery	1
Creative work	1
Working life in general	3
Discipline	
Engineering sciences	11
Social sciences and humanities	6
Computer/data/information sciences	4
Medical sciences	1
Value-base	
Human factors	17
Efficiency	8

The frame analysis then focused on the values underlying the appraisals. Viewing the statements as representing different perspectives in robotisation discourse, the analysis examined how the frames of discourse are constructed according to their value base and disciplinary tradition.

RESULTS

Statements on the theme of working at a robotic pace were quite uncommon in reflections on everyday discussions on the subject. The majority of the data came from the current decade, more specifically from statements published between the years 2020 and 2023. This implies a growing interest in the topic of working at a robotic pace.

The primary result of the content analysis was the statements that were divided into three thematic appraisal categories: positive, negative and neutral views towards working at a

robotic pace. Negative appraisals were the most common. In some mostly critical statements, working at a robotic pace was considered almost more as a metaphor than a reality, describing the impossible demand of ultimate effectiveness. In some statements, the working pace of a robot was framed in a more simplified manner—as a robotic feature described as either positive or neutral in its effectiveness. The initial assumption that working at a robotic pace would be considered as an ideal and the mentions referring to effects of either positive or negative, was proven inaccurate. The statements in which working at a robotic pace was appraised positively due to the increase in efficiency held robotic pace as an ideal. However, the statements in which working at a robotic pace was appraised negatively due to compromised human factors did not hold working at the pace of a robot as an ideal but rather as an excessively mechanistic picture of our working life. In one of the statements, the maximum robotic pace was even considered unreasonable for both humans and robots (Guan & Liao, 2015).

The consistency between the value base of human factors and negative appraisal, as well as the value base of effectiveness and positive appraisal, was nearly perfect. Ethical values stood out as rationalising criticisms in social science discourses, not in engineering sciences discourses, which supported the set hypothesis. However, against the conservative hypothesis made, the data did not show a systematic divide, where discourse found in engineering sciences would include positive appraisals, and discourse found in social sciences would include negative appraisals. If anything, a division was found between the negative and neutral statements. Neutral statements from the social sciences and humanities discourses were non-existent.

Positive appraisals were few in number and closely connected with neutral appraisals because neither denied the value of robots' efficiency. However, frame analysis found a pattern differentiating positive appraisals from neutral ones. Whereas positive appraisals justified working at a robotic pace in a technologically deterministic manner, neutrality appeared to be a force in constructive and problem-solving discourses.

Frames and their Forces

In frame analysis, the themes comprised three identifiable value-laden frames. Working at a robotic pace was framed from a justifying, criticising or problem-solving perspective in the data. The results are shown in Figure 1. The considered forces creating the frames (Entman, 1993: 52) were the themes from before: the nature of the appraisal, context, discipline and value base. The publication year did not prove to be a significant force in the preliminary examination. Hence, the time of study was not included as a force in the final output. In the preliminary content analysis, the value base was divided into human factors and efficiency. In further frame analysis, human factors were categorised in more detail as ethical, reskilling, well-being and incompatibility issues.

Value base was considered the most consistent force behind the varying discourses. First, the discourse justifying working at a robotic pace relied on the technologically deterministic ideal of robotic speed. Second, the discourse criticising the idea of working at a robotic pace identified risks in a range of human factors. Third, the problem-solving discourse stood out with the overall widest value base, underlining its position as the least aligned frame of the three.

Justifying Robotic Pace

The efficiency value was the only actual force, in addition to positive appraisal, that was appointed to the frame of justifying robotic pace because of the small amount of data. The statements coded as positive towards working at a robotic pace valued efficiency in rationalising their perspective. This was identified as a frame of justifying working at a robotic pace. Working at a robotic pace was justified by the rationality of productiveness, where the maximum working pace is ideal and anything below that is likely to be identified as the bottleneck in production:

> Industry aims at accelerating production to operate more in real time and in feature of the overall product lifecycle, where pace is critical for everyone. (Fasuludeen *et al.*, 2022)

Criticising robotic pace

The frame criticising working at a robotic pace attributed forces of negativity towards working at a robotic pace, human factors as the value base, context of industrial manufacturing or working life in general and discourse found in social sciences. In the strength evaluation of the forces, context was considered the weakest and was left out of the figure presenting the main findings. The force was found to be weak for the reason that robots are dominantly used in industrial manufacturing, so the finding was hence redundant.
The critical discourse on working at a robotic pace centred around human factors, and the reasons were based on ethical issues, reskilling and well-being at work. The discourse on work ethics found in the social sciences focused on the inhumanity of placing workers alongside robots and expecting them to adapt to the robotic pace: 'What happens to those who cannot maintain robots' pace?' (Rosenmeyer, 2020).

Reskilling and reorganising work were other reasons underlying such criticism. In the rather future-oriented arguments, robotisation was predicted to deskill professionals and transform work into more routine-based tasks, thus making it less rewarding. In a negative scenario, people were viewed as competing with robots—if not over jobs, then over working speed:

> Development actors ought to consider how embodied intelligence can assist humans, for example, by freeing them to conduct more complex and meaningful tasks or by providing recommendations instead of simply replacing them or forcing them to keep up with the faster pace of robots or drones. (Addo *et al.*, 2021)

Well-being, as the third reason repeated in the data, referred to stress originating from robotisation and intensified work. Although mental stress and cognitive workload were most emphasised in the statements, well-being was framed as an overall risk:

> Organisational hazards, on the other hand, concern repetitive tasks performed at the pace of robots/cobot, potentially causing fatigue, musculoskeletal stress, psychological stress, and physical overload. (Costantino *et al.*, 2021)

In addition to the main reasons listed above, when working at a robotic pace was criticised from the perspective of engineering sciences, people having to adapt to robot-like efficiency was described as incompatible or unrealistic.

Problem-solving robotic pace

First, neutral appraisals were categorized for the seemingly nonaligned views on working at a robotic pace, which quite coherently, were observed as not having a strong value base behind their neutrality. For example, in Bourcier *et al.* (2017), surgeons were plainly stated as already working at almost a robotic pace. Next, in the frame analysis, the neutral statements were found to share a coding of 'robotic pace adaptation'. Aside from being neutral, the discussions offered a constructive viewpoint: Working at a robotic pace is neither a positive nor negative *per se* but something that has to be adjusted to be just right for human safety and job satisfaction.

The neutral statements were framed as problem-solving discourse where value neutrality was complemented by the idea that robots are not only capable of superior speed but also of adapting their speed to an appropriate level. Two of seven adaptation codings consisted of discourse on synchronising robot and human working pace for efficiency and three for human factors. Two quotes consisted of discourse on both efficiency and human factors. These double-coded statements included deliberations on the safety of an employee working together with a robot.

Problem-solving discourse was found in engineering, computer, data and information sciences research. Engineering sciences were the most dominant domain for problem-solving discourse and, moreover, relatively neutral in their discourse, in general. As for context in the problem-solving frame, aside from industrial manufacturing, robotising was discussed in relation to construction work and working life in general. Context was again excluded from the final output because it was the weakest force in frame creation.

All in all, the problem-solving frame attributed forces of neutrality and technology-oriented sciences to working at a robotic pace. AI was found to play a part in the problem-solving discourse. The adaptability of increasingly intelligent robots was viewed as a solution to enable good socio-technical working conditions:

> Learning automaton suitably adjusts the production pace of the robot, thus influencing the dynamics of the cooperation. (Messeri *et al.*, 2021)
>
> Giving the operator the possibility to set the robot's pace and choose the favoured mode of interaction with the robot increased usability and reduced perceived workload, as a sense of familiarity and predictability could be achieved. (Zimmer *et al.*, 2022)

The problem-solving discourse in engineering sciences acknowledged human factors in robotisation and alluded to references across disciplines. Most of these citations, however, were methodological references on monitoring or measuring workload. These cross-discipline citations can be viewed as a quite moderate deviation from the traditions of the natural sciences.

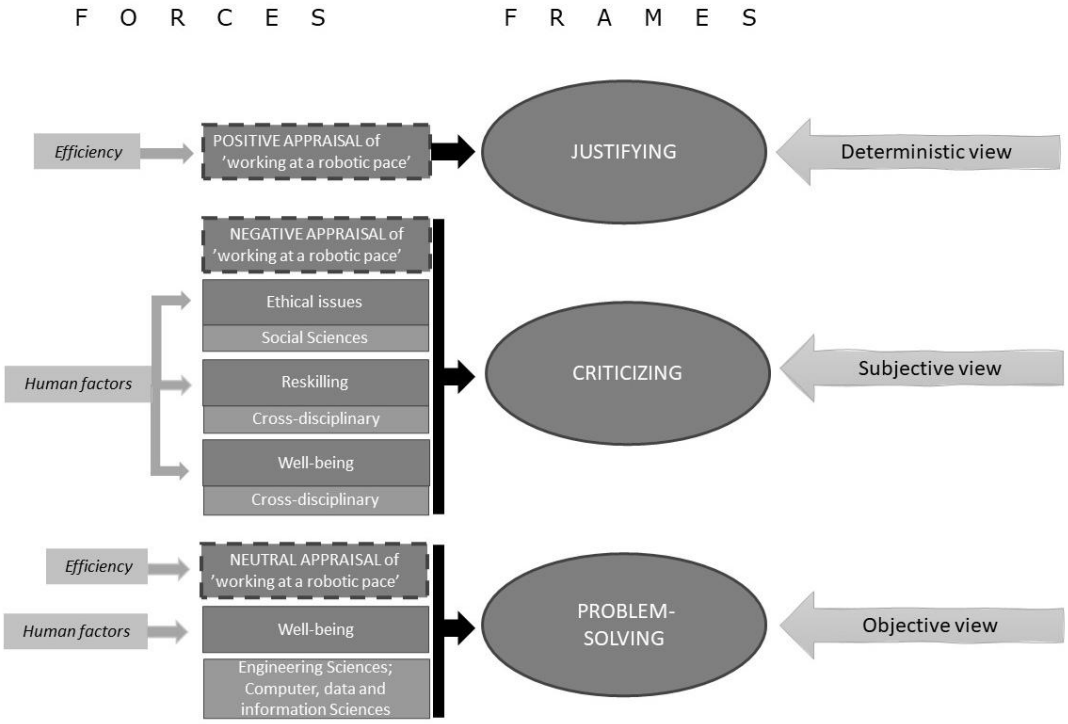

Figure 1. Value-laden discourses on 'working at a robotic pace' framed as justifying, criticising or problem-solving.

DISCUSSION

This study aimed to discern how the ideal of working at a robotic pace is appraised in academic communications. The ideal of robotic pace was understood as originating from a culture bound to the rationality of the mechanical clock (Mumford, 2010), underlying the idea that robotisation belongs on the continuum of mechanical clock time that underscores a mechanical society. Using content–frame analysis, this study examined academic writings involving a statement about 'working at a robotic pace'. The content was classified according to the statement's appraisal of the idea of working at a robotic pace, the value base underlying this positive, negative or neutral view, the robotisation context in question and the scientific discipline of the author.

The findings went against the presumption of robotic pace being a continuation and an embraced accelerator of the clock-centred culture. The idea of working at a robotic pace has received criticism, not only for it being a tall order for human workers but also as a symbol of intensified working life. Furthermore, the discourse on synchronising robot and human working pace not only included the idea of increased pace for efficiency but also moderated the pace for human needs. Although clock time runs Western societies, it seems the line is drawn at the idea of people working at a robotic pace.

However, there were different value-laden discourses on the theme of working at a robotic pace. The study identified three frames in which working at a robotic pace was discussed from a justifying, criticising and problem-solving perspective. Over half of the statements were framed as criticising the idea of working at a robotic pace. Forces of the criticising discourse were negative appraisals of the idea of working at a robotic pace and a value base of human factors. Ethical issues were emphasised in humanistic studies, whereas the human factors of reskilling and well-being did not have disciplinary emphasis. While this finding supports the existing understanding, as far as the idea that ethical issues are a topic for the humanities is concerned (Habermas, 1997; Östlund, 2004), it also reveals that human factors are an acknowledged force in the engineering discourse. In the critical communications produced by those with a technologically oriented background, robot pace was viewed as a challenge when it comes to reorganising work and maintaining well-being at work.

Quite unexpectedly, the neutral appraisals stood out as the most interesting category, featuring discourse on problem-solving the discrepancy between human and robot working paces. This constructive perspective with a neutral, or at the very least balanced, value base was found only in the communications pertaining to technologically oriented disciplines. Despite the diversity in the framing of the phrase 'working at a robotic pace', the role of disciplinary traditions was not as dominant as was initially assumed. It was not only humanistic studies to commit epistemologically to human factors of robotisation. In the discourse originating from the technologically oriented disciplines, human factors were not limited to issues of the availability of skilful labour but also included humanistic values of employee well-being and motivation. The diversity among disciplines in selecting and including relevant research topics and angles is the first implication of socio-technical principles being a viable factor in robot studies in the technological domain.

Deterministic, Subjective and Objective Views

The frames justifying, criticising and problem-solving robotic pace can also be interpreted as deterministic, subjective and objective views on the matter. Technological determinism in this context refers to how working at a robotic pace is an ideal not to be questioned. If a technological solution is available to make work more (cost-)effective, it will be realised. If there is an actor who is not willing or able to act as a supportive force in the proceeding course of technologisation, they form a predicament to be addressed and hopefully turned (see Gregor, Chandra, Kruse, & Seidel, 2020). The deterministic view associated with the statements appraising robotic pace in an unambiguously positive way was rare.

On the contrary, the frame of critical discourse was the most common. The critical discourse on working at a robotic pace is suggested to be associated with a subjective view. In the taxonomic contradiction between subjectivity and objectivity in research, 'subjective' should be understood here as the more interpretative outlook on the research topic. In subjective research, researchers draw from their experiences and insights and focus on the phenomena from the perspective of the study subjects (Williams, 2019: 56–60). Subjectivity and affect in producing knowledge are emphasised in the social sciences and humanities (Hillersdal et al., 2020). This arises from the perspective where societal (research) problems

typically underlie the status quo, and finding them requires a critical approach instead of observing and measuring changes in plain sight.

Competing with this notion, the subjective view was also observable in the engineering science data. The discourse on well-being at work adopted a human-centered approach in numerous studies with a critical view of working at a robotic pace. However, the difference lies in knowledge-constitutive interests. Cognitive interest in truth can be associated with the engineering sciences and the social sciences and humanities because both disciplines seek to uncover truths. Yet, only the social sciences and humanities aim to disseminate truths about robotisation to make ethical evaluations, emphasising their knowledge-constitutive interest in moral correctness.

Neutral appraisals framed as problem-solving discourse are interpreted as building an even stronger bridge between engineering and the humanities. Because of the neutral or balanced view on values associated with robotising work, the problem-solving discourse is suggested to be associated with the most objective view. The problem-solving frame, derived from technologically oriented disciplines, can be viewed as looking past the epistemological traditions of disciplines where the engineering sciences are expected to measure the effective use of machines and the social sciences are expected to focus on the human(e) factors (Léna, 2012). This does not even refer to how boundaries are overcome in multidisciplinary research projects but rather the openness to a multi-epistemological approach in defining research questions within one discipline (Crawley, 2019). In multi-epistemology, the engineering sciences also take account of the human factors in technology development. In this interpretation, disciplinary independence and openness translate into a higher level of objectivity.

In the research topic of academic discourse on working at a robotic pace, the production of objective knowledge represents expert judgment outside of a regulatory setting (Laurent & Thoreau, 2019). Such objectivity is derived from experts viewing a phenomenon from their scientific backgrounds and from how they have learned a certain performance of objectivity (Cook, Turnhout, & van Bommel,, 2020). In the case of working at the pace of a robot, objectivity is neutrality, where using robots is rationalised only because it is the status quo. It is notable, however, that this identifying objectivity of natural sciences (Léna, 2012) is associated with appraising working at a robotic pace neutrally more often than positively.

Indeed, the socio-technical approach was evident among the statements made by scholars from the engineering sciences. According to the data, the engineering sciences acknowledged the need for a symbiosis between the objective of making production more efficient and maintaining a pleasant pace of work. The problem-solving discourses focusing on both human factors and efficiency reflected the language of socio-technical ideals. Thus, the engineering sciences emphasise not only practicality but also instrumental rationality. While practicality is reflected in either technological determinism where almost a naïve view is that production speed is everything or in the more constructive view where robots can be programmed to act at a pace and style that is acceptable for co-working humans, more holistic rationality is also evident in engineering studies.

Although neutrality and the socio-technical perspective were expressed more in the technologically oriented disciplines than in the social sciences, this finding is not perhaps that arresting. The engineering sciences traditionally dominate robotics studies because robotic technology would not exist without engineering. As a consequence of this ascendancy, the

social sciences have played a role in criticising the status quo. Whereas the engineering sciences are expected not to turn a blind eye on human and social factors when it comes to technological developments, social scientists do not have the similar burden of needing to elaborate on the technological aspect of, say, robotisation. This is especially the case when the subject of the study is as provocative as 'working at a robotic pace'. Furthermore, differences in research tasks play a part in this discrepancy between disciplines. The investigative function of the engineering sciences typically focuses on a single technology, whereas in the social sciences, the use of this technology is viewed from a wider and societal perspective. The narrower research subject in the engineering sciences reflects the possibility of adopting a wider theoretical perspective. A more holistic research subject in the social sciences requires a more carefully defined perspective. A classic way to direct qualitative and humanistic research is to say a lot about a little rather than to cover a broad set of determinants to 'cover all potential aspects of the phenomena' (Rapley, 2022: 265, citing Silverman, 2010).

Finally, the findings revealed that the discourse on synchronising robot and human working pace varied in terms of who is setting the pace. In the justifying, or deterministic, frame, studies discussed people adjusting their working pace to robots (Huber et al., 2013), whereas in the problem-solving, or the objective, frame, robots were viewed as being reprogrammed to be convenient for the needs of human workers (Liu & Jebelli, 2022). Additionally, between these opposing perspectives, Benbya, Pachidi, & Järvenpää (2021) described 'employees needing to adjust to the pace of robots' operation rather than being able to set their own pace'. Both discourses originated in engineering sciences, but whereas the study from 2013 laid the flexibility demand on humans, the latter study from 2022 saw an opposite dynamic in working at a robotic pace. Overall, the findings did not point to any general temporal correlation in the data.

Aside from the publication year, the context proved to be an insignificant force behind the discourse surrounding working at a robotic pace. The main reason for this is that robot use is centralised in industrial manufacturing. When academic discussions and studies on service robots reorienting our working lives become more common in the future, cross-context research will also become more feasible as well as relevant. As a limitation of the current study, the number of statements was modest, and the scope of contextual variation left something to be desired.

CONCLUSIONS

To conclude, this study found a small but growing number of statements about 'working at a robotic pace' related to studies on robotising work. All found statements published over a 35-year period were systematically collected and used as data in content–frame analysis. The statements were mostly excised from recent publications in the 2020s. This study's novel value comes from its utilisation of content–frame analysis to uncover meanings and discourses related to robotic working pace. Content analysis encompassed consideration of linguistic features, sources, audiences and intent of discourse. The specific content–frame analysis in the study identified dominant frames shaping interpretations of the robotic pace concept.

The academic discourses drew on a range of perspectives in their representations of working at a robotic pace. Discourse on working at a robotic pace can be classified into three frames, each with a different value base. Statements justifying robotic pace are based on efficiency and technological determinism. Statements criticising robotic pace are based on more subjective concerns over work and AI ethics, such as ethical norms, reskilling or deskilling employees and well-being at work. Statements discussing the problem-solving robotic pace are based on multiple values resulting in neutrality and objectivity. Following the socio-technical principle, problem-solving discourse has deliberated on how human–robot collaboration can be optimised through a robotic pace made more flexible than unreasonable.

The study showed that the research task of considering well-being in robotised work is not confined to the social sciences. While the findings did not repeat the previously acknowledged gap between the natural sciences and humanities, they revealed evidence of multidisciplinary approaches within a single discipline. In problem-solving discourse found across technologically oriented disciplines, robotic pace was described not as a deterministic force but as a challenge to be tackled by technological means to build optimal working environments. Focusing this way on both human factors and efficiency, the findings spoke the language of socio-technical ideals applied providently in the engineering, computer, data and information sciences.

Implications

The study's breakdown of appraisals into justifying, criticising and problem-solving frames, backed by a value base analysis, contributes to understanding diverse perspectives on robotic work pace. It also underlines the relevance of employees' involvement in the design and implementation of robotisation because the best expertise on work and work pace lies on those who are involved with the concrete, daily work (Siderska & Alsaqoor, 2023).

As a scientific contribution, the findings in this study provide a useful framework for research on human–robot interaction, especially work-related robot acceptance. Socio-technically oriented study designs should include value-based evaluations in addition to more traditional measures of human factors. Alongside physical and psychological workload and user experiences in robotising work, empirical studies would benefit from including work and AI ethics in their study designs.

Furthermore, outside academia, this study highlights the multidimensional perspectives that shape discussions around robotic work pace. There are pressing questions about how existing social practices affect the cultural ideal of working at a robotic pace. Optimising collaboration between humans and robots is understood as a universal value that would have a positive influence on both efficiency and human values.

ENDNOTES

[1] See also: What is the difference between academic journals and scholarly (peer-reviewed) journals? *EBSCO Connect* (2018). https://connect.ebsco.com/s/article/What-is-the-difference-between-Academic-Journals-and-Scholarly-Peer-Reviewed-Journals?language=en_US

[2] How hard will the robots make us work? *The Verge* https://www.theverge.com/2020/2/27/21155254/automation-robots-unemployment-jobs-vs-human-google-amazon

[3] Why I was wrong to be optimistic about robots. *Financial Times* https://www.ft.com/content/087fce16-3924-4348-8390-235b435c53b2

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Appendix

Data Descriptives

			Themed codings				
Nb	*Reference*	*Quote*	*Nature of appraisal*	*Value base*	*Primary reasoning*	*Robotisation context*	*Discipline*
1	Addo PM, Verhulst S, Young A, Zahuranec AJ, Baumann D and McMurren J. (2021)	Development actors ought to consider how embodied intelligence can assist humans, for example, by freeing them to conduct more complex and meaningful tasks or by providing recommendations, instead of simply replacing them or forcing them to keep up with the faster pace of robots or drones.	Negative	Human factors	Deskilling	Working life in general	Data science
2	Arntz A, Di Dia A, Riebner, T Eimler SC (2021)	However, since prior studies revealed that the speed of the robot is crucial for the collaboration setup, lowering the working pace of the robot, which is already perceived as slow, is no option.	Neutral	Efficiency, human factors	Necessity, adaptation	Industrial manufacturing	Computer science
3	Beillon K and Wramsby W (2012)	In other words, to replace human beings in environments where there is high risk to health and safety, or in tasks where humans cannot keep up with the pace of a robot.	Positive	Efficiency	Necessity	Industrial manufacturing	Production development
4	Benbya H, Pachidi S and Jarvenpaa S (2021)	For example, employees may need to adjust to the pace of robots' operation rather than being able to set their own pace.	Neutral	Efficiency	Adaptation	Working life in general	Information systems and business analytics
5	Bourcier T, Chammas J, Becmeur PH, *et al.* (2017)	Robot-assisted surgery has expanded over the past 20 years in macrosurgical specialties; however, microsurgical specialties have seen little growth in the field. The main reasons for this discrepancy include that cataract surgeons work at a nearly robotic pace by routinely performing up to 20 procedures per day, the surgical robots are not specifically microsurgical robots, and the cost of robotic systems.	Positive	Efficiency	Inessential	Medical surgery	Ophthalmology
6	Corlett EN (1988)	The effects on people when they are set to work with robots are similar to those caused by the old paced assembly line. The operator works at the robot's pace, all the time the robot works, and of necessity on a repetitive task with limited content.	Negative	Human factors	Deskilling	Industrial manufacturing	Production engineering
7	Costantino F, Falegnami A, Fedele L, Bernabei M, Stabile S and	Organizational hazards, on the other hand, concern repetitive tasks performed at the pace of robots/cobots, potentially causing fatigue, musculoskeletal stress, psychological	Negative	Human factors	Stress and well-being	Industrial manufacturing	Mechanical and aerospace engineering

	Bentivenga R (2021)	stress, and physical overload, as well as additional damages caused by a monitoring decrease.					
8	Dhillon BS (1993)	One problem arising from robotization is the incompatibility in terms of work pace with humans	Negative	Human factors	Incompatibility	Industrial manufacturing	Engineering management
9	Ellegård K (1999)	The (unexpected) positive social effect of this technically motivated buffer was that the workers were not completely bound to the pace of the robots. The buffer, however, was not installed for social reasons but for technical reasons in the case of machine break-down.	Negative	Human factors	Incompatibility	Automotive industry	Human and economic geography
10	Fasuludeen Kunju FK, Naveed N, Anwar MN and Ul Haq MI (2022)	Moreover, industry aims at accelerating up production to operate more in real-time and in feature of the overall product lifecycle, where pace is critical for everyone, digitizing document flows, being able to react faster in case of production issues, and so on.	Positive	Efficiency	Production speed	Industrial manufacturing	Computer and information sciences
11	Grant BK (1997)	Chaplin's tramp caught in the gears of the conveyor belt after struggling to maintain the inhuman robotic pace of the assembly.	Negative	Human factors	Inhumanity	Interpretation of a fictional scene of industrial manufacturing	Communication and film studies
12	Guan Y and Liao H (2015)	Time allowances are created to take into consideration fatigue and other factors that affect human employees, creating more realistic time standards instead of assuming a robotic pace that would otherwise be unachievable by a person working 8 hours a day. In terms of machines, allowances are also incorporated to take into account down times and other aspects such as cool downs or inspections. These realistic times allow for a better estimate to what a line can produce without the expense of operator health and machine lifetime.	Negative	Human factors	Unrealistic	Industrial manufacturing	Industrial engineering
13	Huber M, Lenz C, Wendt C, Färber B, Knoll A and Glasauer S (2013)	Each assembly step has a fixed time interval, so the human worker needs to adapt to the robot pace… The experiment subjects do not adjust their working speed to the pace of the robot. Instead they keep their preferred assembly behavior, which results in varying waiting times.	Positive	Efficiency	Adaptation	Industrial manufacturing	Sensorimotor research
14	Liu Y and Jebelli H (2022)	Another example is when workers are subjected to excessive cognitive load due to the working speed of robots. The robot will not adjust its pace to reduce the cognitive load; this imposition can cause mental fatigue and stress… When workers are under high cognitive loads, the Co-Path allows robots to provide an	Neutral	Human factors	Stress and well-being, adaptation	Construction sites	Architectural engineering

		enhanced sense of safety by staying a comfortable distance away from workers and gives them more stress recovery time by reducing the robot's pace.					
15	Liu Y, Habibnezhad M, Jebelli H and Monga V(2021)	Task #2 was designed to examine the performance in adjusting the working pace of the robot based on workers' cognitive load	Neutral	Human factors	Adaptation	Construction sites	Architectural engineering
16	Mateos JM (2019)	As the robots carry the pods quicker, the whole process is speeding on, and pickers have to do their job even faster, following the pace of the robots. The robots have raised the average picker's productivity… Robots are designed to accelerate the work process, but humans have physical limits, and sooner or later they will suffer from the commitment to follow such an inhuman pace… Because as it happened in the assembly line the Kiva robots, and other systems are the ones that set the pace of work, and the workers have to follow it.	Negative	Human factors	Inhumanity	Warehouse work	American studies
17	Messeri C, Masotti G, Zanchettin AM and Rocco P (2021)	We propose a novel paradigm where the robot is enabled to adapt its behavior online to simultaneously optimize in real time human physiological stress and productivity. The proposed control strategy exploits a game theoretic approach to model and locally estimate the state of collaboration in terms of human productivity and stress. Based on this estimate, a learning automaton suitably adjusts the production pace of the robot, thus influencing the dynamics of the cooperation.	Neutral	Efficiency, human factors	Adaptation	Industrial manufacturing	Bio engineering
18	Rosenmeyer A (2020)	Are we willing to be cogs in the machine of the emerging post-industrial age? Whose machine is it? Will that truly make us winners, and what happens to those who cannot maintain robots' pace?	Negative	Human factors	Inhumanity	Creative work	Art
19	Turja T, Hakanen J, Krutova O and Koistinen P (2023)	This not only applies to knowledge work and the ever-growing service sector where the work pace has been accelerated, but also to industrial manufacturing where automation has made work faster, endorsing the speed of robots… Whereas working at a robotic pace is easy to categorize as a negative stressor, high demands of digitized work can have either a hindering or a challenging effect	Negative	Human factors	Stress and well-being	Industrial manufacturing	Social sciences
20	Turja T, Minkkinen J	Technological systems and computer software have a higher probability to	Negative	Human factors	Deskilling	Working life in	Social sciences

	and Mauno S (2022b)	increase workers' autonomy at work while a robotic device entails always a risk of work changing to mechanistic and more routine-based in nature. In such case, the working pace of everyone is connected to the working pace of a robot.				general	
21	Zanchettin AM, Marconi M, Ongini C, Rossi R and Rocco P (2020)	Nowadays, synchronisation between humans and robots and the corresponding turn-taking is explicitly controlled, via command channels, such as a switch or a button. Synchronisation does not necessarily entail a rendezvous between the two agents, but can also require to adjust the pace of the robot according to the one of human.	Neutral	Efficiency	Adaptation	Industrial manufacturing	Bio engineering
22	Zimmer M, Al-Yacoub A, Ferreira P, Hubbard E and Lohse N (2022)	Giving the operator the possibility to set the robot's pace and choose the favoured mode of interaction with the robot, increased usability and reduced perceived workload as a sense of familiarity and predictability could be achieved.	Neutral	Human factors	Adaptation	Industrial manufacturing	Software engineering

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EFFECTIVENESS OF NEUROFEEDBACK-BASED COGNITIVE TRAINING IN OLDER ADULTS

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Abstract: *The increasing aging of the global population requires strategies that address age-related cognitive decline. This study investigated the impact of neurofeedback (NF) training on cognitive performance in healthy older adults, those with mild cognitive impairments (MCI), and those with mild dementia (MD). Participants engaged in bi-weekly NeuroPlay training over 4 weeks, targeting theta/alpha brainwave frequencies. The results revealed intriguing distinctions: ACE-III scores significantly improved in the MCI ($p < 0.001$) and MD ($p = 0.004$) groups, signifying robust enhancements in attention, memory, and language. MCI participants displayed notable gains in digit span tests ($p = 0.014$) and participants' Continuous Performance Task results indicated fewer errors ($p = 0.003$). Meanwhile, reaction times in the Simple Reaction Time task increased ($p = 0.047$) for healthy participants. These findings underscore NF's potential to enhance cognitive functions, particularly in attention-related tasks, suggesting its efficacy as an intervention tool for age-related cognitive decline.*

Keywords: *neurofeedback, mild cognitive impairment, mild dementia, cognitive training*.

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INTRODUCTION

The global population is aging at an alarming rate. The number of elderly people is expected to increase from 10% in 2022 to 16% in 2050. Furthermore, the number of people 65 years of age or older is forecast to be more than twice the number of children under 5 (United Nations Department of Economic and Social Affairs Population Division, 2022). With increased longevity and an aging population, the prevalence of age-related disorders, including cognitive and motor dysfunctions, is bound to rise (Podhorecka et al., 2021).

Deterioration of cognitive functioning is a natural age-related process that may contribute to several limitations. The most noticeable differences are observed in attention, memory, and executive functions, essential for independent living, communication, and sensory integration. This type of cognitive decline is most frequently associated with neuronal dysfunction or neuronal loss, which may also make it challenging to learn new abilities, impair short-term memory, working memory, decision-making, or multitasking (Murman, 2015; Wojciechowski et al., 2021).

Cognitive performance in older adults can be effectively stimulated by cognitive training that is increasingly becoming computerized (computerized cognitive training, CTT). CTT has gained considerable popularity as a safe, relatively affordable, and customizable intervention tool for maintaining cognitive functioning in older adults (Hill et al., 2017). Compared to traditional interventions, it allows for the use of single or multiple domains of cognitive functioning with flexible adaptation of exercises to the patient's performance and provides real-time performance feedback (Hill et al., 2017; Lampit et al., 2014). In addition, computerized training is characterized by situational accuracy as it refers to everyday life skills with multidimensional interfaces. Such visually appealing interfaces are well suited for the elderly and are intended to be enjoyable, exciting, and motivating for further training programs (Zając-Lamparska et al., 2019). Recent studies have demonstrated the effectiveness of CTT in healthy older adults and individuals with mild cognitive impairment (MCI) by stimulating neuroplasticity (Hill et al., 2017; Kueider et al., 2012; Lampit et al., 2014). However, such computer-based interventions have noted limitations, particularly in terms of modern technology accessibility among the elderly and the use of CTT in dementia patients. Therefore, there are a growing number of emerging trends in cognitive training, especially with the use of biometric sensors (Stavropoulos et al., 2020).

Neurofeedback (NF) is a method applicable to cognitive training. It is a non-invasive technique that promotes self-regulation of brain function by using real-time displays of neural activity, most frequently with electroencephalography (EEG). NF is a closed-loop application that can help control or modify cortical activity. Individuals are exposed to visual and/or auditory stimuli, representing various frequencies of bioelectrical brain activity that are recorded by sensors located on the scalp; thus, they can actively participate in the regulation of their brain activity with this type of training (Laborda-Sánchez & Cansino, 2021). The training aims to increase attention and memory and lower anxiety (Marlats et al., 2020). Recent studies have shown the effectiveness of NF in hyperactivity disorder, epilepsy, autism, depression, and anxiety.

NF is also widely used in cognitive training with specific training protocols targeting frequency bands related to cognitive functioning. The first studies incorporating NF effects on memory were conducted with young adults (Lecomte & Juhel, 2011). The training condition

was stimulation of alpha waves (8–12 Hz, related to the relaxation) (Bauer, 1976) or theta waves (4–7 Hz, connected to the working memory) with inhibition of delta waves (< 4 Hz, associated with sleep) (Vernon et al., 2003). Another protocol applied stimulation of sensorimotor rhythm (SMR) waves (12–15 Hz, related to attention) and inhibition of beta (18–22 Hz, associated with anxiety) (Vernon et al., 2003). Further studies showed that, generally, alpha/theta training can result in an improvement in cognitive performance in young adults (Hanslmayr et al., 2005).

NF has been widely used to improve cognitive function in various age groups. In children, NF is most commonly used to improve attention, impulsivity, and hyperactivity, with a series of studies providing evidence for the positive effects of NF in attention deficit hyperactivity disorder (ADHD). The most widespread protocol is theta/beta training where the goal is to decrease activity in the theta band and to increase the beta band in the frontal cortex. For this protocol, a decrease in behavioral problems and improved cognitive performance have been reported (Gevensleben et al., 2009; Heinrich et al., 2004; Strehl et al., 2017). In healthy adults, increasing the power of SMR brain waves has been reported to improve attention, memory, and executive function (Gruzelier, 2014). This protocol with 30 to 40 treatment sessions has also been reported to be effective in adults with ADHD (Arns et al., 2014). The latest findings have shown that NF is also useful to reduce reaction time and improve the cognitive performance of adult athletes. Nonetheless, no standard protocol has been found among the studies, as most of them used different frequency bands and different locations to measure the effect of NF (Brito et al., 2022).

Although the impact of NF on cognition has been established, only several studies have been conducted on the application of NF among older adults (Lecomte & Juhel, 2011). Comprehension of neural activity in the elderly is essential for the development of NF protocols. Peak alpha frequency (PAF) is known to be weaker in children, the elderly, and individuals with Alzheimer's disease; thus, available protocols related to the PAF are on the rise.

Increases in PAF have been noticeable in frontal lobe brain areas after 30 NF sessions; this result was related to the enhancement of the speed of information processing, memory performance, and the resistance to interference (Angelakis et al., 2007). Alpha training lasting 10 days has also been confirmed to improve the flexibility of executive functions in patients after stroke (Reichert et al., 2016). In another study, a short and intensive alpha/theta NF protocol demonstrated that an intervention consisting of 30-minute sessions for 8 days improved cognition, especially short-term memory (Reis et al., 2016).

The role of the SMR/theta protocol was also investigated (Marlats et al., 2020). The average training period was 10 weeks, with two sessions each week. Results suggested that such training could be beneficial in reducing cognitive decline in the elderly.

SMR NF is suggested to facilitate thalamic inhibitory mechanisms and block motor activity that interferes with information processing; hence, it is claimed to improve working memory and attention in older adults (Kober et al., 2015). Working and short-term memory have also been enhanced by SMR training (Compos da Paz et al., 2018; Gomez-Pilar et al., 2016). Moreover, verbal ability increased during the protocol in Becerraa et al. (2011).

A systematic review of the effects of NF on memory in older people with cognitive decline observed that NF improved memory in both healthy and MCI people, particularly when the SMR/theta protocol was investigated (Laborda-Sánchez & Cansino, 2021). In general, there

was no effect on the attention process. In contrast, another review revealed that NF can also increase attention functions in the elderly (Jiang et al., 2017), so its role in attentional capacity remains unclear.

NF protocols have been reported to improve cognition in older adults in at least one domain. The protocols distinguished between alpha/theta and SMR/theta protocols, with SMR waves obtaining more significant results (Laborda-Sánchez & Cansino, 2021). The current study aimed to investigate the role of NF training in cognitive performance in healthy older adults and those with MCI or mild dementia (MD).

METHODS

The study sample was recruited from various assisted living communities. The approval of a Bioethics Committee was obtained. The longitudinal design was evaluated. Participants were selected based on a medical diagnosis and Mini-Mental State Examination (MMSE) scores, with 27–30 points indicating normative cognitive function, 24–26 points indicating MCI, and 19–23 points indicating MD. Written consent was obtained from all qualified participants, and in the case of individuals with dementia, their caregivers also provided consent.

All participants underwent a neuropsychological assessment twice: a pretest conducted 3–7 days before training sessions using NeuroPlay, and a posttest conducted 3–7 days after the completion of the training. The NeuroPlay training sessions took place twice a week for 4 consecutive weeks. Each study session lasted approximately 45 min; the NF training itself lasted 21 min and consisted of six phases: alternate periods of eyes closed (2 min) and eyes open (5 min, active attention training). Thus, one training session comprised three 7-minute micro-cycles. The training protocol utilized a theta/alpha-based algorithm, promoting the increase of averaged theta [4–7] and alpha [8–12] frequency band values, as well as the theta/alpha ratio for the O1 and O2 areas (occipital leads), with the Fp1 and Fp2 areas (frontal leads) treated as control regions for the final comprehensive analysis. More specifically, Fast Fourier Transform (FFT) was used to algorithmically analyze the transmitted data. The algorithm consisted of key steps such as downloading data for selected channels, recalculating the data for each electrode using the FFT algorithm, calculating weighted averages from the given frequency ranges and then calculating their difference. In the next step, the data for each electrode were compared with the data calculated in the previous steps (shifting the reading frame), and then the data were summed and mapped, ultimately leading to a specific value of the fit factor parameter (ffx), which controls the animation and sound in the training games. NeuroPlay training used a headband fitted with ten EEG sensors placed around the circumference of the head, in a system corresponding to the standard electrode arrangement for EEG measurement in the 10-20 model. In practice, the headband was wirelessly connected to the tablet via a Bluetooth 5.0 connection and the NeuroPlay application installed on the tablet. In the Neuroplay solution, the headband is a measurement device, while the processing and decision algorithm is implemented in an application on the tablet. The main electronics of the headband (PCB with radio module, battery, USB-C input) were placed on the back of the head.

Study Methods

The study was performed using the following neuropsychological tools: (1) the MMSE to test time orientation, attention, verbal memory, language functions, and visual-spatial analysis; (2) Addenbrooke's Cognitive Examination III (ACE-III), a screening test composed of tests of attention, orientation, memory, language, visual perceptual, and visuospatial skills; (3) the Color Trail Test (CTT) to assess psychomotor speed, attention, spatial ability, and executive functions; (4) the forward and backward Digit Span Test (DST) from WAIS-R (PL) to assess attention and verbal short-term and working memory; (5) the Digit Symbol Coding (DSC) task from WAIS-R (PL) to examine learning abilities, attention, short-term memory, and visuospatial skills; (6) the Go/No-Go test to measure psychomotor speed, sustained attention, and response control; (7) the California Verbal Learning Test (CVLT) to measure the ability to learn and remember verbal material; (8) the Continuous Performance Task (CPT) to examine sustained and selective attention; and (9) the Simple Reaction Time (SRT) to assess the ability to sustain attention over a prolonged period of time.

Participants

A total of 190 participants comprised the sample. The individuals were divided into groups based on cognitive status and whether they participated in NF training (experimental group) or traditional paper-and-pencil cognitive training (active control group). Among people without cognitive impairments, the experimental group consisted of 53 participants (27 females; age: M =71.075, SD = 5.207; years of education: M = 14.430, SD = 4.591), while the active control group included 17 participants (14 females; age: M = 73.882, SD = 5.999; years of education: M = 13.647, SD = 3.570).

Among individuals with MCI (mild cognitive impairment), the experimental group included 52 participants (37 females; age: M = 74.442, SD = 6.014; years of education: M = 12.212, SD = 2.696), while the active control group consisted of 11 participants (six females; age: M = 73.091, SD = 5.029; years of education: M = 13.900, SD = 3.929).

Among individuals with MD (mild dementia), 48 participants were in the experimental group (30 females; age: M = 77.583, SD = 6.731; years of education: M = 12.177, SD = 2.790), while nine participants were in the active control group (eight females; age: M = 77.111, SD = 5.487; years of education: M = 12.556, SD = 2.455).

Statistical Analyses

ANOVA tests were used to assess cognitive functioning differences before and after training, considering NF or traditional cognitive training. Separate analyses were conducted based on cognitive status subgroups. A repeated measures ANOVA was used for single-indicator measurement tools, while a repeated measures MANOVA was used for multiple indicators. Univariate analyses were performed when a MANOVA showed significant differences, and post hoc tests were performed for specific pairwise differences.

RESULTS

In this section, only statistically significant differences between the cognitive performance prior to and after the test will be discussed. In all groups, no significant differences were observed in the following tests: CVLT, Go/No-Go task, DSC, and CTT. Additionally, within the healthy group, there were no significant differences in the forward and backward DST, MMSE, and ACE-III. In the group with MCI, there were no significant differences in the forward and backward DST after traditional cognitive training and the SRT independent of the type of training. For the MD group, no significant differences were found in the CPT and SRT, regardless of the training type.

Differences in the Pretest and Posttest Screening Scores (MMSE, ACE-III)

Significant differences in cognitive performance were observed between people with MCI ($F = 14.320$, $p < .001$, partial $\eta 2 = 0.19$) and MD ($F = 9.370$, $p = .003$, partial $\eta 2 = 0.15$), while no significant differences were found in those with normal cognitive functioning. These differences were independent of the type of training. However, for individuals with MCI, significant differences were found between pre-training and post-training ACE-III scores (Wilks' lambda = 0.763, $F = 3.538$, $p = .007$, partial $\eta 2 = 0.24$), indicating improvements, particularly in the attention domain ($F = 14.844$, $p < .001$), regardless of the training type. Similarly, among people with MD, significant differences were observed between the first and second measurements of ACE-III measurements (Wilks' lambda = 0.714, $F = 4.002$, $p = .004$, partial $\eta 2 = 0.29$), with significant improvements in memory ($F = 15.429$, $p < .001$) and language functions ($F = 7.491$, $p = .008$), regardless of the type of training. Table 1 refers to the significant results of the MMSE and ACE-III tests obtained among individuals differing in cognitive status before and after the training.

Table 1. Significant Differences in MMSE and ACE-III Scores Obtained Among Individuals Differing in Cognitive Status Before and After the Training, Accounting for the Type of Training Implemented.

Test/Group	**Neurofeedback training**		**Traditional cognitive training**	
	Pretest *M* (*SD*)	Posttest *M* (*SD*)	Pretest *M* (*SD*)	Posttest *M* (*SD*)
MMSE				
MCI	25.404 (0.634)	26.558 (1.650)	24.909 (0.831)	25.727 (1.348)
MD	21.500 (1.305)	22.979 (2.893)	21.222 (1.093)	22.111 (1.167)
ACE-III Attention				
MCI	15.788 (1.073)	16.577 (1.391)	14.000 (2.191)	14.818 (2.040)
ACE-III Memory				
MD	12.438 (4.491)	14.213 (4.530)	13.556 (3.844)	15.667 (2.739)
ACE-III Language				
MD	20.917 (3.432)	21.660 (3.074)	20.889 (2.977)	21.778 (2.728)

Note. MCI – mild cognitive impairment, MD – mild dementia.

Differences in the Pretest and Posttest Digit Span Test (DST) Scores

No significant differences were found in the DST across all groups, irrespective of the training type. However, in the MCI group, a near-significant interaction effect between measurement and training groups prompted further univariate analyses. These analyses revealed significant differences in the forward DST between pre- and post-training measurements, depending on the type of training (F = 6.498, p =.014). However, post hoc analysis showed a statistically significant improvement in the NF training group (p =.008), while the decrease in the active control group was not statistically significant (p =.633). Table 2 refers to the significant results obtained in the DST.

Table 2. Significant Differences in WAIS-R Scores Obtained Between MCI-Positive Individuals Before and After Training, Accounting for the Type of Training Carried Out

Test/Group	**Neurofeedback training**	
	Pretest *M* (*SD*)	Posttest *M* (*SD*)
Forward Digit Span Test		
MCI	4.904 (1.176)	5.327 (1.410)

Note. MCI – mild cognitive impairment.

Differences in the Pretest and Posttest Continuous Performance Test Scores

Analyses with CPT scores were conducted with smaller sample sizes due to incomplete data. The analysis included 36 healthy individuals (25 neurofeedback, 11 active control), 42 individuals with MCI (36 neurofeedback, six active control), and 38 individuals with MD (35 neurofeedback, three active control). Among healthy individuals, an interactive effect of measurement time and training type was observed in the total number of errors (F = 9.963, p =.003). A post hoc analysis revealed a significant increase in errors after NF training (p =.044), while traditional training did not yield a statistically significant change. In the MCI group, significant differences were found between pre- and post-NF training measurements. Univariate analyses showed that the total number of errors was the only performance indicator affected by this interaction (F = 9.963, p =.003), with better results after the training. In the MD group, there were no statistically significant differences between the results of the pre-and posttest. Table 3 refers to the significant results obtained in the CPT.

Table 3. Results from the CPT Obtained Among Individuals With Varying Cognitive States in the Measurement Before and After Training, Considering the Type of Training Conducted.

Test/Group	**Neurofeedback training**	
	Pretest *M* (*SD*)	Posttest *M* (*SD*)
Error numbers		
CN	0.960 (1.513)	1.640 (1.469)
MCI	1.972 (3.009)	1.083 (1.052)

Note. CN – cognitive norm, MCI – mild cognitive impairment.

Differences in the Pretest and Posttest Sustained Response Task (SRT) Scores

Analyses of SRT scores were carried out with smaller sample sizes due to incomplete data. The analysis included 35 healthy individuals (24 neurofeedback, 11 active control), 40 individuals with MCI (35 neurofeedback, five active control), and 36 individuals with MD (33 neurofeedback, three active control). In healthy individuals, a significant change was observed in the second measurement compared to the first (*Wilks' lambda* = 0.826, F = 3.374, p =.047, partial $\eta 2$ = 0.17), specifically an increase in the average reaction time (F = 6.253, p =.018) regardless of the training type. No significant changes were observed in individuals with MCI or MD due to NF training. See Table 4 for detailed results.

Table 4. Significant Results from the SRT Obtained Among Individuals in Healthy Adults in the Pre-Training and Post-Training Measurements, Accounting for the Type of Training Performed

Test/Group	Neurofeedback training		Traditional cognitive training	
	Pretest *M* (*SD*)	Posttest *M* (*SD*)	Pretest *M* (*SD*)	Posttest *M* (*SD*)
	Average reaction time (in ms)			
CN	1460.785 (763.387)	1557.394 (702.305)	1392.709 (771.427)	1833.441 (589.416)

Note. CN – cognitive norm.

DISCUSSION

The present study aimed to investigate the effects of NF (neurofeedback) training on cognitive performance in older adults with different cognitive performances. The results obtained indicate that NF training may have selective effects on specific cognitive domains and may not improve performance on all cognitive tasks (see Table 5).

Table 5. Summary of the Results Obtained.

	Neurofeedback training			Traditional cognitive training		
	CN	MCI	MD	CN	MCI	MD
MMSE	-	+ ↑	+ ↑	-	+ ↑	+ ↑
ACE-III	-	+ ↑	+ ↑	-	+ ↑	+ ↑
CTT	-	-	-	-	-	-
DST	-	+ ↑	-	-	-	-
DSC	-	-	-	-	-	-
Go/No-Go	-	-	-	-	-	-
CVLT	-	-	-	-	-	-
CPT	+ ↓	+ ↑	-	-	-	-
SRT	+ ↓	-	-	+ ↓	-	-

Note. CN – cognitive norm, MCI – mild cognitive impairment, MD – mild dementia, (+) – significant difference between pre- and posttest, (-) – no significant difference between pre-and posttest, (↑) – better obtained results within the difference, (↓) – worse obtained results within the difference.

Interesting results were obtained with the MMSE and ACE-III screening tests, which showed significant differences between pretest and posttest scores in individuals with MCI and MD, regardless of the type of training. These screening tools are considered sensitive to cognitive changes in individuals with cognitive decline (Kourtesis et al., 2020), thus no differences in scores in healthy subjects seem reasonable. In the ACE-III, the MCI group improved in attention, while those with MD achieved progress in both memory and language function. Such enhancement was acquired both in NF and traditional cognitive training, which indicates that any brain stimulation—understood as cognitive activity—may stimulate overall cognitive ability measured by screening tools (Liu et al., 2016). Furthermore, the social aspect may also have influenced the results in the experimental and active control groups, as both groups had direct contact with the researcher. Phenomenologically, MCI and MD appear to bring a lower quality of life, more frequent depressive symptoms, and avoidant coping strategies compared to healthy older adults (Bárrios et al., 2013). Researchers indicate that loneliness predicts cognitive decline and the risk of developing dementia (e.g., Freak-Poli et al., 2021), therefore social interactions are perceived as a promising intervention for improving cognitive function, especially for language functions (Dodge et al., 2015).

The results obtained also suggest that NeuroPlay training may have beneficial effects on the ability to maintain and manipulate information in short-term and working memory in individuals with MCI. Specifically, MCI individuals showed improvement in the DST (Digit Span Task) after NF training. These findings are partially in line with previous studies that indicate older individuals with MCI can improve specific aspects of EEG activity, leading to improvements in working memory and processing speed (Lavy et al., 2019). Studies focusing on training the alpha brainwave frequency showed significant improvements in short-term memory and working memory tasks, including the DST (Digit Span Test), highlighting the potential role of alpha training in cognitive performance (Hsueh et al., 2016).

Furthermore, the MCI individuals improved in the CPT (Continuous Performance Task), which is sensitive to sustained and selective attention. Subjects made fewer errors after NF training, implying that they paid more attention to the tasks, indicating that NF is also helpful for attention enhancement (Cho et al., 2004).

Notably, no differences were observed in the Go/No-Go test across all groups, regardless of the type of training. Although both tasks are designed to assess complex attentional functions, the CPT is more sensitive to response inhibition, which is thought to be better evaluated by the theta components that were targeted in the NF protocol employed in this study (Kirmizi-Alsan et al., 2006). Moreover, the findings hold particular relevance as research suggests that deficits in attentional processes may underlie the development of episodic memory loss—a hallmark of dementia in Alzheimer's disease. Therefore, the observed protective role of NF training in mitigating further cognitive decline in people with MCI is noteworthy (Malhotra, 2019).

In the analyses of the healthy subjects' group, the reaction time in the SRT (Simple Reaction Time) task increased significantly regardless of the type of training. Furthermore, the number of errors in the CPT (Continuous Performance Test) increased in the NF group. It should be noted that both tasks are designed to assess sustained attention. Previous research suggested that older individuals exhibit slower responses to stimuli compared to younger individuals, a phenomenon that has been attributed to a reduction in alpha wave power in EEG

tests (Gajewski & Falkenstein, 2014; Porciatti et al., 1999). Nevertheless, researchers have indicated that increasing the alpha wave power in NF does not decrease participants' reaction time (Woodruff, 1975). Conversely, augmenting the power or amplitude of faster brain frequencies, such as the SMR (sensorimotor rhythm, 12–15 Hz), and increasing beta waves in the 13–30 Hz range, may lead to faster reaction times (Egner & Gruzelier, 2004). From a neurophysiological standpoint, it is known that shorter response times are associated with heightened EEG oscillatory activity and increased arousal levels, although this association does not necessarily lead to more accurate responses. Enhancements in alpha wave power can improve accuracy on the CPT, as evidenced by a reduction in errors. However, these enhancements tend to slow down reaction times, particularly in the SRT task, due to a decrease in arousal (Mirifar et al., 2022), although this hypothesis was not confirmed in the present study.

Among normal-aging subjects, there was a significant increase in the number of errors after NF training, as well as a substantial increase in reaction time during the second measurement of the SRT task. It can be hypothesized that motivation plays a significant role in explaining this phenomenon. In the context of cognitive tasks, older adults frequently exhibit a heightened sensitivity to motivational factors in comparison to their younger counterparts (Ennis et al., 2013; Hess, 2014). In the present study, participants underwent a repeated administration of tasks that were relatively straightforward and could have lacked engagement during the posttest session. This potential lack of engagement might have contributed to the observed decline in performance.

Recent studies indicate that theta and alpha bands serve as important indicators of cognitive abilities in older adults, suggesting that changes in these frequency bands are likely predictive of cognitive impairments (e.g., Trammell et al., 2017). Consequently, the theta/alpha NF protocol may be more beneficial for people with MCI (mild cognitive impairment) compared to healthy adults, which may explain the lack of general differences observed in the current study between the cognitively normal group. Furthermore, the MD (mild dementia) subjects demonstrated improvements only on our screening tools, including the MMSE and ACE-III. Dementia symptoms encompass a range of cognitive impairments including memory loss, language difficulties, anxiety, depression, and personality changes (Trambaiolli et al., 2021). The available studies that focus on the role of NF in MD implemented protocols that included 10 to 96 training sessions (Surmeli et al., 2016; Trambaiolli et al., 2021). It is plausible to hypothesize that a greater number of sessions may be necessary for MD patients to show improvements in more sensitive neuropsychological measures.

NF has been reported to improve cognition in older adults in at least one domain (Laborda-Sánchez & Cansino, 2021), typically focusing on improvement in a specific cognitive domain, as each brain wave is associated with different cognitive functions. Different protocols are employed for improving specific cognitive functions. For example, alpha waves are connected with relaxation and mental coordination, theta waves are linked to working memory, SMR waves to motor control and attention (De, Mondal, 2020).A significant body of work has linked alpha- and theta-band activity with attention (Foster et al., 2017; Guo et al., 2020). This supports the observation that only attention-related task performance improved in individuals with MCI (mild cognitive impairment).

In general, this study found that NF training had selective effects on cognitive performance in older adults, with improvements seen in specific cognitive domains. Aligning with previous

studies, the theta/alpha protocol was related to improvements in attention domains. The findings highlight the potential of NF as an intervention to enhance cognitive function, especially in individuals with MCI. The social aspect of training and the role of brain wave frequencies in cognitive abilities were also discussed.

The study has several limitations. In our study, the active control groups were smaller than the experimental groups, which may affect the generalizability of the results, as unequal group sizes can increase the margin of error. in addition, as mentioned before, the weakening of some indicators (SRT and CPT) after neurofeedback therapy may be related to the lack of engagement with these particular tasks, which was another limitation of the study. It is possible that the repetitive nature of these tasks led to decreased motivation over time. Moreover, SRT and CPT are considered to be tedious and less attractive tasks, so the greater risk of loss of engagement is not necessarily due to neurofeedback itself. Despite these limitations, the present study provides valuable insights into the effects of NF training on cognitive performance in older adults with different cognitive abilities, suggesting the NF as an intervention for cognitive enhancement in aging populations. Further studies with larger groups are required to confirm and understand the full impact of NF training on cognitive achievement in older people with diverse cognitive functioning. It would also be valuable to investigate whether the observed improvements in cognitive performance are sustained over time. Future studies should also consider controlling for potential confounding variables that could influence the results, such as the use of medications by participants, comorbidities, or lifestyle factors.

CONCLUSIONS

The study revealed that NF training selectively improved certain cognitive domains in older adults, particularly those with MCI. Notably, improvements were observed in attention-related tasks for MCI individuals. Screening tools, such as the MMSE and ACE-III, showed significant differences in individuals with MCI and MD, suggesting improvements in attention, memory, and language function.

The theta/alpha NF protocol appeared more beneficial for those with MCI. To further understand NF's impact, future research with larger samples, long-term follow-ups, and control for confounding variables is recommended. Despite limitations, the study highlights NF's potential for enhancing cognitive function in older adults, especially those with cognitive impairments, through tailored protocols. Such tailored protocols are designed to meet the specific needs of each individual, rather than applying a generic treatment approach. It includes adjusting the neurofeedback training to target specific brainwave patterns that are linked to cognitive functions. For instance, increasing alpha wave activity can help improve relaxation for individuals who experience stress-related cognitive impairments or increasing theta wave activity can improve memory and attention.

IMPLICATIONS FOR THEORY

The research reveals that NF training has specific benefits on several cognitive domains. In an age where the world's population is getting older, training that is specifically targeted at

particular cognitive domains, as this study has shown, has the potential to improve cognitive functioning and potentially slow down age-related cognitive decline.

The study also highlights the complex interactions between cognitive domains by revealing an intriguing idea: cognitive activity as a type of brain stimulation. This realization might completely change our knowledge of cognitive processes and how to use them to enhance cognitive function as a whole. The study also emphasizes how important motivation and engagement are for cognitive training, particularly for older persons. Understanding the importance of these variables might help develop more successful cognitive interventions that are suited to the particular requirements and traits of the elderly population, thereby promoting improved cognitive well-being as the population ages.

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CONSUMER EMOTIONS, PURCHASING DECISIONS, SHOPPING TIME, AND PATHS IN VIRTUAL REALITY

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Abstract: *This article presents virtual reality research findings on customer emotions, product choice, store time, and distance traveled. Advanced tools, such as virtual reality and EEG technology, were used, as well as both qualitative and quantitative approaches. Data is primarily derived from participants contributing to a broader research project that analyzes both conscious and unconscious aspects. The study revealed that emotions significantly impact purchases in vegetables, fast food, and baked goods sections, with correlations to customer distance in the virtual store. The study is limited by the high data collection cost restricting the sample size. Nevertheless, these findings can guide future researchers interested in this technology. Store managers can leverage these insights to enhance sales strategies and store layouts, aiding customer decision-making. This study attempts to provide a fresh perspective on the research problem by integrating virtual reality (VR) and electroencephalogram (EEG) equipment in the Fast-Moving Consumer Goods (FMCG) sector, offering new results that have not been previously published.*

Keywords: *emotions, consumer behavior, virtual reality, purchasing decision, shopping time and paths.*

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INTRODUCTION

The current breadth of knowledge about consumer behavior in the market is the result of empirical research conducted over the past few decades and the evolving views on consumption, consumers, and their market behavior (Karabiyik & Elgün, 2022; Oszust & Stecko, 2020; Perez-Vega, Hopkinson, Singhal, & Mariani, 2022). Consumer "circulation" in two worlds - real and virtual – is becoming an important research subject. From a scientific point of view, therefore, it is now crucial to get to the source of information, i.e., the human brain. It is thus interesting to study how behavior and emotions in the real world are transferred to the virtual world. Modern technological solutions make it possible to study and observe internal factors and indicators of behavior. Examples include such methods as eye tracking, virtual reality, and electroencephalogram (EEG) devices. It is also possible to combine different tools to get results from different internal impulses (Biercewicz, Chrąchol-Barczyk, Duda, & Wiścicka-Fernando, 2022). Eventually, an alternative methodology was employed, whereby applied research methods were integrated into the analytical process and EEG and VR devices were combined. This approach yielded a new application of these tools. By integrating VR technology with EEG data collection, researchers have gained deeper insights into the neural processes behind emotions and decision-making in a more immersive and realistic setting (Hofmann et al., 2021; Jung, Choi, Kim, Cho, & Han, 2022). This innovative approach has paved the way for exploring how people engage with virtual environments and how their emotional states impact their behavior (Basbasse et al., 2023; Xie, Chiang, Xu, & Gong, 2023). Moreover, combining EEG with VR has allowed researchers to detect neural emotional states triggered by interactions in virtual environments, providing a deeper understanding of the dynamics of human emotions in immersive contexts (Jin, Kim, Moore, & Rothenberg, 2021; Sun, 2023). Additionally, integrating EEG data with inertial sensing has demonstrated potential to enhance subject-independent emotion classification in VR, underscoring the possibilities for improving emotion recognition through advanced technological integrations (Wan et al., 2021).

As a result of the evolution of consumer behavior research, there are numerous definitions of the concept, and contemporary definitions are usually not assigned to a single scientific discipline and are interdisciplinary (Babin & Harris, 2023; Baumgartner, 2002; de Mooij & Hofstede, 2011). As one of the comprehensive definitions of consumer behavior, we can point to M. de Mooij's definition (de Mooij, 2019), in which research elements are exposed, such as attributes of the person and the decision-making process indicating the use of psychology and sociology; analyzing and managing choices, which indicates the viewpoint of sciences such as management and economics; and values and culture, which are the result of using cultural studies for analysis.

Of particular importance in modern consumer behavior research, as already mentioned, is psychology, which uses scientific research on human, social, cognitive, and emotional factors to better understand the behavior of individuals. A psychological approach to consumption research has pointed to the need to recognize the consumer's psychological profile in analyzing his market behavior. This profile is the influence on market behavior of the consumer's personality, attitudes, habits, opinions, motives, emotions, norms, and values, which are a set of intangible factors (Haugtvedt, Herr, & Kardes, 2008; Mullen & Johnson, 2013; Schiffman, O'Cass, Paladino, & Carlson, 2013).

The contemporary stage of research on consumer behavior, especially consumer purchase decision-making, which took shape in the 21st century, is not uniform and consistent. Attempts are being made to categorize concepts, analyze information processing, study consumer loyalty and experience, and capture consumer ways of thinking in patterns (Halkias, 2015; Ishak & Abd Ghani, 2013; Jain, Aagja, & Bagdare, 2017; Novak & Hoffman, 2009; Zaltman & Zaltman, 2008).

Analyzing the emotions that accompany market decisions has also become an important aspect of consumer behavior research, which has continued since the 1980s (Achar, So, Agrawal, & Duhachek, 2016; Foxall, 2011; Hirschman & Stern, 1999; Laros & Steenkamp, 2005; Niedzielska, 2016; Richard, Zynep, & Joseph, 2002; Williams et al., 2014). Emotions are also believed to be an important factor influencing consumer behavior including time spent in the store and moving through store aisles. This factor belongs to the group of internal factors related to the consumer's person, which are individual and subjectively affect decision-making (Pawle & Cooper, 2006). Individuality means that consumer behavior cannot be 100 percent predicted.

Emotions, from a psychological point of view, denote a set of changes including physiological arousal, feelings, cognitive processes, and behavioral reactions that occur in response to a situation that an individual perceives as important (Foxall, 2011; Izard, 1991; Reisenzein, 2007; Williams et al., 2014). In addition to emotions, affect and mood are also distinguished. Emotions are short-lived, involve a specific object or subject, and can be very intense (O'Shaughnessy & O'Shaughnessy, 2002). Moods are long-term in nature, are not tied to a specific situation or subject, and their intensity is lower than that of emotions (Ekkekakis, 2012). Affect, on the other hand, is a positive or negative very short-lived reaction, often automatic and not subject to control (Achar et al., 2016; Ekkekakis, 2012; Laros & Steenkamp, 2005; Williams et al., 2014).

The emotions that accompany consumers in their shopping and purchasing decisions can also result from, be shaped by, or be stimulated or mitigated by the impact of other direct and indirect determinants (Mullen & Johnson, 2013; Szymańska, 2017; Verduyn, Mechelen, & Frederix, 2012). The role of emotions is evidenced by the fact that more than 80% of decisions are made under the influence of emotions (Rahmanian, 2013)

Explaining consumer behavior before making a purchase decision, or the motives behind the choice is a complicated process (Khan, Rezaei, & Valaei, 2022). According to a study conducted at the University of Amsterdam, simple decisions are made with thought, and complex decisions are made intuitively (Haslam, 2007). Emotionally driven purchases are most common in the FMCG product group (Matysik-Pejas & Szafrańska, 2011).

In addition, emotions can not only determine the choice of a product or brand, making the final purchase decision, but also how long the customer will stay in the sales location, or what distance he will travel to find the right product, in his opinion. The existing literature offers a multitude of definitions of emotions, as well as a detailed account of the aforementioned issues. (Achar et al., 2016; Alsharif, Md Salleh, & Baharun, 2021; Ceccacci, Generosi, Giraldi, & Mengoni, 2018; Dawson, Bloch, & Ridgway, 1990; East, Lomax, Willson, & Harris, 1994; Gaur, Herjanto, & Makkar, 2014; Guo, Wang, & Wu, 2020; F. Hansen & Christensen, 2007; Hui, Inman, Huang, & Suher, 2013; McDonald, 1994; Petrosky-Nadeau, Wasmer, & Zeng, 2016; Spanjaard, Young, & Freeman, 2014; Wang, Guo, Wu, & Liu, 2019). Therefore, conscious companies, more and more actively, meet the

emotional attitudes of consumers by creating a positive consumer experience with a product or brand (Dimitrakopoulos, Uden, & Varlamis, 2020).

Technological developments create new opportunities for consumer emotion research. Nowadays, not only observation is used, but also tools that study emotions through brain waves (electroencephalogram) (Amran et al., 2022), voltage and eye movements (Eyetracking) (Chernyak, Chernyak, Bland, & Rahier, 2021), or pulse (pulse meter), but also brain image (CT scanner) or the most modern real-time emotion recognition (Minaee, Luo, Lin, & Bowyer, 2021), or in augmented reality (de Amorim, Guerreiro, Eloy, & Loureiro, 2022). Synergy in getting information from different sources when it comes to emotions is key to understanding what the consumer is feeling, for example, when shopping (Spanjaard & Freeman, 2012).

Important in designing the consumer experience is the place of purchase and the arrangement of the sales area, so that the entire store is conducive to converting potential customers into buyers and staying in the store as long as possible and to encouraging the consumer to navigate using the greatest number of shopping paths or routes. Such activities are referred to as Visual Merchandising (VM) also called the "silent selling technique" (Park, Jeon, & Sullivan, 2015). VM can be used by retailers in various categories, and after the strong development of modern technologies, also in the areas of e-commerce (Eroglu, Machleit, & Davis, 2003; Swanson & Everett, 2015). There is a discussion in the literature on the distinction between Visual Merchandising and 'store atmosphere' or 'atmospherics' where the differences and similarities of these concepts are shown (Basu, Paul, & Singh, 2022). This article assumes, following the authors indicated earlier, that these concepts are different but interact to form an integral store environment. VM creates a product strategy that relates to a particular brand, shelf, or entire store area. It is about display based on a product that is important to both manufacturers and retailers. Atmosphere refers to areas of the store and will refer to the activities carried out in its domain therefore the display throughout the store (Bhatt, Sarkar, & Sarkar, 2020).

The presented article attempts, based on research conducted in virtual reality, to determine the relationships occurring between customer emotions and product choice, time spent in the store, and distance traveled.

METHODS

Determining the relationships that exist between customer emotions and product choice, time spent in the store, and distance traveled was the goal of the study.
Three research questions were posed:

1) In virtual reality, do emotions influence purchase decisions?
2) In virtual reality, do emotions influence the longer time spent at the point of sale?
3) In virtual reality, do emotions influence the longer distance traveled at the point of sale?

In this research, we investigated the relationship between consumer emotions and various factors influencing purchase decisions within virtual shopping environments. The independent

variable of interest was the emotional state of the consumers, while the dependent variables included the time taken for decision-making (H_1), the duration spent in the virtual store (H_2), and the distance covered within the virtual store (H_3).

This study employed a qualitative research approach to explore the complex interplay between consumer emotions (independent variable) and dependent variable: H_1 the time it takes to make a purchase decision; H_2 time spent in the virtual store; H_3 the length of distance traveled in the virtual store.

Data was gathered from a sample of 30 participants, making use of innovative research tools, namely the EEG apparatus (electroencephalography) and VR technology. The study was qualitative in nature, and a simple random sampling method was employed.

The data collection process involved the utilization of EEG technology to capture participants' brainwave patterns and emotional responses, providing valuable insights into their emotional states. Additionally, VR technology was employed to immerse participants in a virtual shopping environment, enabling a realistic shopping experience that closely mimics real-world interactions.

The type of research was a qualitative study method, where the data was collected from 30 respondents.

The authors used the following research method: descriptive statistics: mean, Pearson correlation coefficient, Index of Arousal, and Valence.

Description of the study

The study followed the research procedure, which is illustrated in Figure 1. To select the sample (N=30), the place of residence was taken into account. Then, the research problem was formulated, which is presented at the beginning of the Methods section.

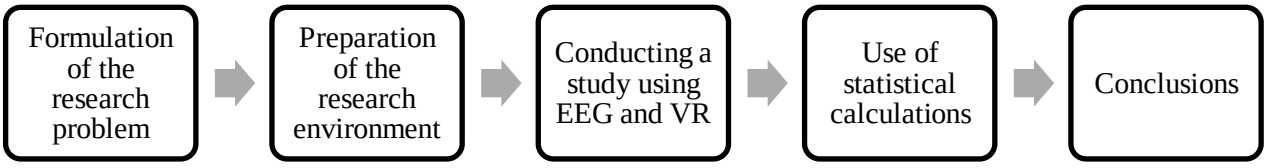

Figure 1. Research procedure

[Source: own collaboration]

The present study used the off-the-shelf store Enzone, which was properly adapted to the research needs and integrated into a VR environment using the Unity engine. The environment was carefully designed to reliably replicate a traditional (FMCG) shopping destination, in such a way as to reflect the real situations that respondents encounter in the real world. Before the study, participants were duly informed of the objectives and nature of the study and voluntarily consented to their participation (the study also received ethics committee approval).

The next step in the study was to present the participants with a short instructional video, which outlined exactly how to move, and pick up objects, and the purpose of the study, which was to do everyday shopping. After watching the instructional video, but before the actual survey, participants had the opportunity to practice the discussed activities in a virtual environment. This allowed them to acclimate and adjust to any disturbances that may have occurred during the study (Li et al., 2020).

Preparing the respondent to participate in the study involved the following steps: Placing the EEG cap (Enobio 20) on the participant's head, performing the connection of electrodes to the scalp, and attaching the HTC Vive Pro Eye virtual reality device.

The study used a cap equipped with EEG electrodes placed at F3, F4, according to the international EEG electrode placement system, known as the 10-20 system (Herwig, Satrapi, & Schönfeldt-Lecuona, 2003). To ensure signal quality and conductivity, the electrodes were placed on the scalp after wetting. To assess the quality of contact between the EEG electrodes and the scalp, impedance values were measured using Neuroelectrics® Instrument Controller (NIC2) software. The sampling frequency was 500 Hz.

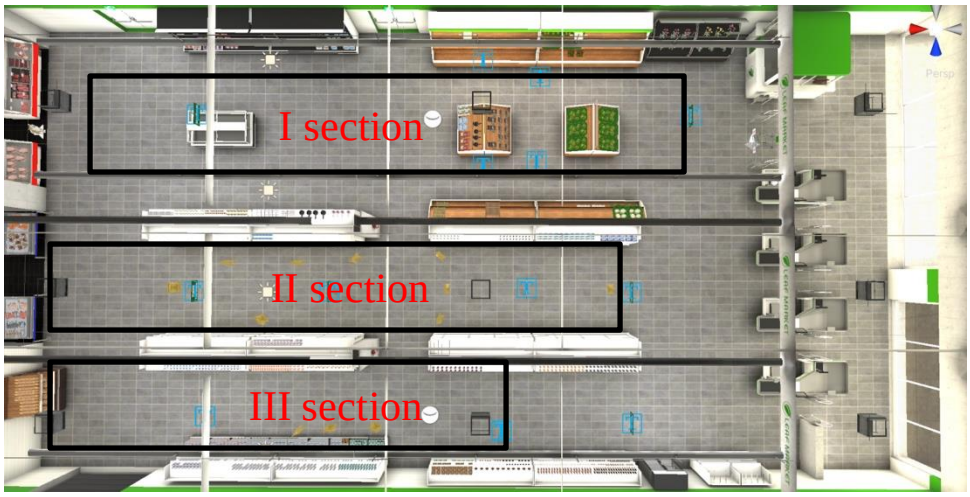

Figure 2. Store appearance

[Source: own collaboration]

The store consisted (see: Figure 2) of three aisles - the first aisle contained products from the fruit, vegetable, dairy, and fast food categories, the second aisle contained fish and beverages, and the third aisle contained baked goods and beverages.

The person navigated the store by using a teleportation method, where they directed their movement with a controller and, upon confirmation, their character was instantly moved to the desired location. This movement technique was implemented to address space limitations and minimize additional artifacts.

Before the respondents entered the virtual store, they were presented with a black screen for 60 seconds to calm their emotions and synchronize the brain waves of the study

participants. All activities performed by the participants were recorded and saved in an Excel file using OBStudio software. The collected data was further analyzed.

Measures

In the initial stage, products were assigned to the following categories: fruits, vegetables, dairy, fish, fast food, baked goods, and water. Using the event file, the respondent's purchasing decisions were determined. The event file contained information about each product taken in hand, the time the product was held, and the decision made by placing the product in the shopping cart. The level of emotion was then calculated, based on the arousal and valence index, which are presented in Table 1.

Table 1. Description of the incdes used in the study.

Name of the Index	Formula	Counting method
Arousal (McMahan, Parberry, & Parsons, 2015)	$\frac{F3_{Beta3} + F4_{Beta3}}{F3_{Alpha2} + F4_{Alpha2}}$	Registration value from electrodes F3 and F4
Valence (McMahan, Parberry, & Parsons, 2015)	$\frac{F4_{Alpha2}}{F4_{Beta3}} - \frac{F3_{Alpha2}}{F3_{Beta3}}$	Registration value from electrodes F3 and F4

The choice of these indicators for analysis is due to their potential use in studying consumer decisions in simulation (Moses et al., 2018; Szymkowiak et al., 2020).

RESULTS

All data from the VR environment was analyzed using Matlab R2019a. Analysis of the EEG signal began with the application of bandpass filtering to remove power grid interference, i.e. frequencies above 50 Hz. In addition, the signal was detrended and subjected to additional filtering using the Fieldtrip library. Then, raw EEG data was inspected for artifacts and noise, which included identifying and removing segments with muscle activity, eye blinks. Next, Independent Component Analysis (ICA) was applied to further isolate and eliminate noise components. Bad channels were identified and interpolated based on neighboring electrodes. Finally, the clean data was re-referenced to a common average to reduce reference-related bias. These preprocessing steps ensured that the EEG signal was of high quality before undergoing detailed analysis. The EEG signal was subjected to a spectral analysis using the Morse transform, which calculated the average peak frequency in periods of the frame (J. M. Lilly & S. C. Olhede, 2010; Lilly & Olhede, 2012; Wachowiak et al., 2018). To determine the alpha and beta frequencies, the signal was divided into the corresponding bands (Tsipouras, 2019) - Alpha (7-13 Hz) and Beta (13-25 Hz).

In the study, the indices presented were used to determine the emotions accompanying participants at specific product sections. In this context, four groups of emotions were

distinguished: emotions of delight (with positive arousal and valence indices), emotions of tension (with positive arousal and negative valence indices), emotions of disappointment (with negative arousal and valence indices), and emotions of lethargy (with negative arousal and positive valence indices).

In addition, calculations were made on the timing of decisions to buy or reject the product, and brain waves responsible for emotions were recorded from the moment of entering the area of the relevant department until leaving it. The results obtained are shown in Table 2.

Table 2. The time to decide on a purchase in a given category and emotions.

	Fruits	Vegetables	Dairy	Fish	FastFood	Baked goods	Drinks
Mean time [s] product purchase	2.30	2.08	1.95	1.46	1.73	1.41	2.10
Mean time [s] product rejection	1.25	1.95	2.21	3.44	2.20	3.62	2.63
Arousal	0.18	0.01	0.30	-0.03	0.40	0.84	0.22
Valence	-0.02	0.17	-0.08	-0.03	0.21	0.01	-0.01

The fastest purchase decisions were made in the bread and fish departments, with an average time of 1.41 sec and 1.46 sec, respectively. In contrast, the time to reject a product purchase in these departments was 3.62 sec and 3.44 sec. In contrast, the longest time to make a purchase decision was 2.30 sec in the fruit department. In contrast, the time to reject a purchase from this product category was the fastest at 1.25 sec.

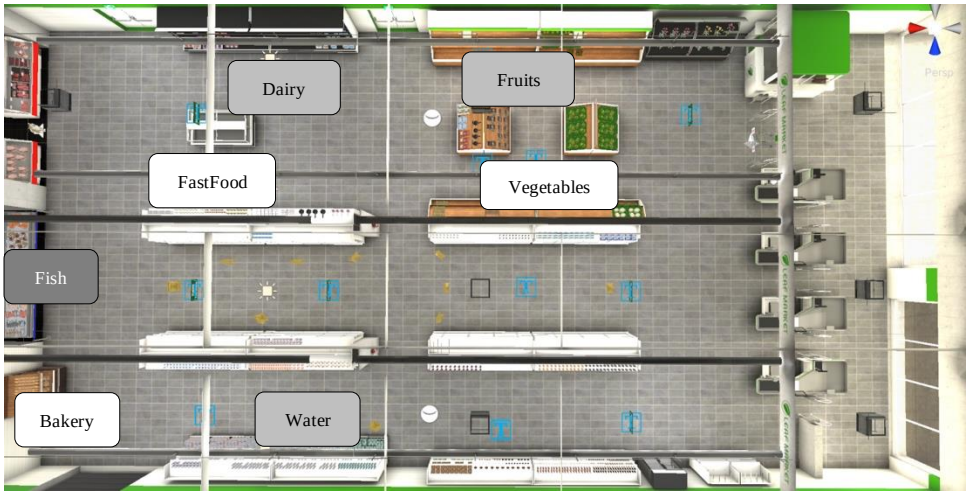

Figure 3. Emotions in individual purchasing departments

[Source: own collaboration]

In addition, it is worth noting (see: Figure 3) that positive emotions were in the vegetables, fast food, and baked goods departments (white color), and negative emotions were observed in the fruits, dairy, and drinks departments (light gray), and discouragement in the fish department. While shopping, each respondent walked an average of 77 meters and spent an average of 557.82 sec in the store.

Next, it was decided to see what average emotions accompanied individual respondents throughout the study. Accordingly, four groups of emotions were distinguished - positive Arousal and Valence scores correspond to feelings of joyful emotions (29% of respondents); positive Arousal and negative Valence scores indicate feelings of anxious emotions (25% of respondents); negative Arousal and Valence scores signify feelings of disheartened emotions (21% of respondents); negative Arousal and positive Valence scores represent feelings of tranquil emotions (25% of respondents).

The final step was to examine the correlation between Arousal, Valence, distance traveled, and time (Table 3). For this purpose, the Pearson correlation coefficient was used.

Table 3. Correlation between Arousal, Valence, path, and time.

Pearson correlation				
	Arousal	Valence	Path	Time
Arousal	1.000000	-0.041836	-0.009367	0.199626
Valence	-0.041836	1.000000	0.380150	0.212219
Path	-0.009367	0.380150	1.000000	0.691528
Time	0.199626	0.212219	0.691528	1.000000

In most cases, a weak or insignificant relationship was obtained. The exception is the relationship between Valence and distance traveled. It was obtained that if the Valence index increases then the distance traveled by the respondent increases moderately ($r = 0.38$). This means that in a situation where one walks a large number of meters in a store positive emotions increase. In the second case, a rather obvious conclusion was obtained, i.e. if the distance traveled in the store increases then we spend more time in the store ($r = 0.69$). A positive strong relationship was obtained in this case.

DISCUSSION

The authors analyzed the results concerning the influence of positive emotions on purchase decisions in virtual reality. In the research conducted, the results obtained confirmed this assumption about 3 product segments, i.e. vegetables, fast food products, and baked goods. The study of the impact of emotions on consumer decisions and behavior has been of interest to researchers for many years. As early as the 1980s, models appeared in which, when analyzing the consumer choice process, a significant role was attributed to emotional processes. Emotions themselves were seen as complex and socially constructed, and it was noted that in many cases the awareness of emotions in the decision-making process is followed by rationalization of purchases (Elliott, 1998). In the case of the studies conducted,

the rationalization was to shelve the product. Emotional perspective has also been studied in the context of assumptions that consumers do not use their cognitive and affective skills independently, but rather influence each other, and results indicated that the affective construct of emotion did not significantly influence purchase intention (T. Hansen, 2005). This assumption was not borne out in the case of the studies conducted, studies have shown that emotions influenced purchases. Still, other studies have looked at the relationship between emotions and choice and perceived risk in the purchase of products and services. It was shown that emotions can violate rational choices and that emotions change under the influence of perceived risk (Chaudhuri, 2002). Subsequent research on deepening the understanding of the impact of emotions on purchasing decisions considered the ethical aspect. In this case, the influence of both positive and negative emotions was studied. The research focused on analyzing present decisions, and in addition, it also determined how present decisions can shape future consumer choices. The study found that a positive-minded consumer will make a more ethical decision, and this experience will result in positive emotions in future purchases (Escadas, Jalali, & Farhangmehr, 2020). The authors' study showed that emotions also had a positive impact on buying decisions. It is also worth mentioning that in the literature one can find studies that indicate that both traditional and modern methods can be used to study the impact of emotions on purchasing decisions. Among others, the observational method and the method of behavioral descriptions are used, which can be used to capture consumers' emotional experiences and can help study both the structure and content of a consumer's emotional experience, recognizing both the conscious and subconscious elements of that experience (Chamberlain & Broderick, 2007). Nowadays, methods of using artificial intelligence to study emotions and consumer behavior are also spreading (Mehralian, 2022; Warszycki, 2019). The authors' study used modern tools such as EEG and VR.

The result obtained on the evaluation of the impact of emotions on the length of time spent by consumers at the site showed that areas where shopping was associated with positive emotions, revealed a moderate correlation between an increase in the Valence index and an increase in the distance traveled by respondents ($r = 0.38$). The results mean that positive emotions affect the distance traveled by customers in a virtual store.

This observation is consistent with research conducted by Forsythe and Bailey (1996), who studied the impact of pleasure on time spent shopping in traditional stores. Their research indicates that this relationship is also related to consumer characteristics other than economic, such as marital status and age. Similar findings were also obtained by researchers analyzing consumer behavior in shopping centers in Vienna. There, they noted a correlation between age and time spent in the mall. Other studies suggest that time spent shopping is also related to gender, with women spending more time shopping than men (Obulesu & Kumar, 2022). In addition, visual merchandising also has a significant impact on time spent in the store (Mihić, Anić, & Kursan Milaković, 2018).

In terms of perceptions of time spent shopping and its impact on customer loyalty, research by Anić et al. (2011). They provide valuable information. These studies analyze not only time itself but also time gaps (misconceptions about the passage of time) and the relationship between time spent in the store to customer loyalty to the store.

In addition, some studies focus on how time affects customer abandonment of online purchases and shopping cart abandonment (Jiang, Zhang, & Wang, 2021; Rajamma, Paswan,

& Hossain, 2009). These results underscore the importance of time as a factor influencing customers' shopping behavior, both in traditional and virtual stores.

It also turns out that emotions affect the distance traveled by the consumer. The customer's movement through the store can provide us with valuable information about whether all products are arranged intuitively, the preferred direction to move through the store, or which department they start shopping from. In the study, it was obtained that emotions affect the extension of time in the store, however, it was not possible to determine what emotions cause this condition. In contrast, in a study conducted by Jin, Kim, and Moore (Jin et al., 2021) positive emotions in the VR store were obtained, which increased the perceived attractiveness of the store. It is worth noting that in this context virtual reality does not mean full virtual interaction, but rather watching 360-degree videos. In this case, the person is not moving around the store, but watching finished footage.

To encourage customers to travel a longer distance in-store and possibly change their traditional shopping path, stores often use various strategies such as product tastings or promotions, including mobile promotions (Hui et al., 2013). In addition, the atmosphere in the store and the level of congestion also affect how long customers stay in the store and how far they travel. If these factors are viewed negatively, customers may reduce their time spent in the store or even decide to leave the store (Hwang, Tung, & Cho, 2023). All of this underscores the importance of both emotions and the store environment in shaping customers' shopping behavior.

It is worth noting that the use of modern tools will increasingly be used to study consumer behavior and especially to study emotions, as consumers value a media-rich environment that helps them make decisions (de Amorim et al., 2022).

Thus, it can be concluded that the results obtained by the authors of the article are in line with the research trend and can add to the existing knowledge on the presented topic of the impact of emotions on purchasing decisions.

CONCLUSIONS

In the article, the obtained results of the study confirmed the influence of emotions on purchase decision-making for three types of products, thus indicating the significant role of emotional processes in the consumer's full-scale decision-making process. The very design of the study proposed in the article and the results obtained are in line with the discussed research trend on the impact of emotions on purchase decision-making and add to the knowledge in this area. On the one hand, the results corroborate the findings of previous studies. However, this also permits the expansion of these investigations through the utilisation of additional innovative research instruments and techniques.

Emotions affect the length of time spent in the store, but it has not been possible to determine which positive emotions extend this time.

When arranging a sales area - a virtual store - appropriately, it is important to build a positive atmosphere in the store, which will build customer emotions, and this will influence a longer "walk" of the customer through the store. Which increases the probability of getting better acquainted with the store's offer.

However, it should be taken into account that for certain participants in the study, the environment in which they were situated, i.e. virtual reality, determined gamer-specific behaviors. The authors posit that this effect could be attributed to the way the VR environment is perceived as a space where the passage of time holds significance. Another constraint lies in the study's scope, which is currently limited to a pilot investigation. To achieve a more comprehensive and accurate representation, it becomes imperative to broaden the sample size. Despite these limitations, the outcomes derived from the study substantiate the viewpoint that there is a correlation between emotions and the length of time spent in the virtual store. The constraint posed by the high cost of data collection and its effect on sample size should be considered in future research.

IMPLICATIONS FOR RESEARCH, APPLICATION, OR POLICY

The results of this study underscore the significance of emotions in influencing consumer behavior within virtual shopping environments. Further research could delve into specific emotional triggers that lead to varying levels of engagement, time spent in the store, and distance covered by consumers.

The conclusions drawn from this study carry practical implications for marketers and companies operating in virtual commercial spaces. Designing virtual shopping environments that evoke positive emotions has the potential to increase customer engagement and encourage longer interaction times.

Furthermore, businesses might consider adjusting the layout of their virtual stores and product placements based on emotional cues to enhance overall shopping experiences and boost sales. As virtual shopping becomes more integrated into the retail landscape, understanding the emotional aspects of consumer behavior can shape policy discussions.

Regulatory frameworks and guidelines could be developed to ensure the ethical use of emotional cues in virtual shopping environments, safeguarding consumer rights and preventing potential manipulation. The implications of this study for research, applications, and policy underscore the importance of emotions in shaping consumer behavior in virtual shopping environments.

The findings of this study contribute to a deeper understanding of how emotional responses influence purchasing decisions, providing opportunities for improved marketing strategies, enhanced consumer experiences, and well-informed policy considerations in the virtual retail landscape.

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