Beyond Legal Compliance: Vulnerability and Active Inclusion in European Urban Digital Twins

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Abstract

Urban Digital Twins (UDTs) are increasingly deployed across Europe for urban planning, resource management and participatory governance. Although applicable data-protection, accessibility, non-discrimination and AI-governance rules establish important safeguards, formal legal compliance does not by itself ensure that structurally marginalized inhabitants can access, understand, shape or contest UDT-enabled governance. This paper distinguishes legal compliance, understood as satisfaction of the binding requirements applicable to particular UDT components and actors, from active inclusion, understood as the affirmative design and governance measures needed to secure effective and equitable participation. Building on disaster-risk assessment methodology, the Digital Citizenship Rainbow (DCR) and legal-philosophical accounts of vulnerability, we conceptualise exclusionary platform design as a hazard and identify five intersecting vulnerability dimensions: digital literacy, structural accessibility, socioeconomic stratification, legal status, and identity and expression safety. We apply this framework through an evidence-informed interpretive comparison of six digital civic platforms. The cases serve as functional analogues and design precedents rather than as a representative sample or legal-compliance audit. The analysis shows that formal availability and protective features can coexist with distributional underrepresentation, expertise barriers and unequal influence. On this basis, the paper argues that UDT governance should be assessed on two complementary fronts: module-specific legal compliance and intersectional active-inclusion. Finally, we position hackability as a demanding form of active inclusion through which citizens can extend, scrutinise and contest UDT infrastructures within appropriate legal and security constraints.

Keywords: Urban Digital Twins, Digital Governance, Vulnerability Assessment, Digital Exclusion, Accessibility, Participatory Design

Relevance statement: This contribution is relevant to AI and data governance because it shows how algorithmic, data-intensive urban infrastructures can entrench digital exclusion unless accountability and participation are designed in from the outset, offering municipal and EU policymakers a concrete vulnerability-aware framework for inclusive AI-enabled governance.

1. Introduction

Cities across Europe are increasingly experimenting with Urban Digital Twins (UDTs) to improve planning, resource management, and civic participation. By linking the physical and digital dimensions of urban life, UDTs promise more responsive governance and new forms of collective decision-making, yet the same infrastructures that hold such promise risk reproducing or intensifying social divides if they fail to include those already marginalized by digital, social, or legal barriers (Ragnedda and Ruiu, 2020). In line with the growing literature that reads UDTs as socio-technical systems rather than purely technical ones (Nochta et al., 2021; Qanazi et al., 2025), this paper argues that their democratic value also depends on how vulnerability and inclusion are addressed from the outset.

A critical but underexplored dimension of this challenge is vulnerability itself: UDTs are frequently designed without a systematic account of which citizens are likely to be excluded, why, and at which state. While EU frameworks such as the General Data Protection Regulation (GDPR)[1], the Data Governance Act (DGA)[2], and the Artificial Intelligence Act (AIA)[3] establish important protections, they fall short of mandating participatory

[1] Regulation (EU) 2016/679 (GDPR). General Data Protection Regulation.

[2] Regulation (EU) 2022/868 (DGA). Data Governance Act

[3] Regulation (EU) 2024/1689 (AI Act). Artificial Intelligence Act.

co-design or targeted outreach to underserved groups. Legal compliance provides a necessary floor, but does not establish whether differently situated inhabitants can effectively access, understand, influence and contest a UDT; these further conditions define what we call active inclusion. "Our contribution is threefold: we adapt and integrate existing frameworks into a conceptual framework for identifying vulnerability in UDT design, framing exclusionary platform design as a hazard source; we document five intersecting vulnerability dimensions creating compound exclusion. Finally, given the scarcity of UDT deployments documented in sufficient empirical detail, we apply this approach to six European civic and participatory digital infrastructures, examining both their compliance-relevant safeguards and their capacity to support active inclusion. We use "civic" to denote platforms supporting residents' engagement with local governance, and "participatory" to denote those offering formal input channels along the Digital Citizenship Rainbow tiers introduced in Section 5. The next section will briefly introduce UDT technology and related issues and promises.

2. Making Sense of Urban Digital Twins

Digital Twins are real-time virtual replicas of physical systems that enable monitoring, simulation, and predictive decision-making (Grieves and Vickers, 2017). UDTs extend this technology to city-scale governance, primarily supporting decision-making processes and enabling resource optimization and emergency planning. Many cities within and beyond the EU are investing in UDTs to optimize resource management, improve operational efficiency, and support smart urban planning (Papyshev and Yarime, 2021). Some European cities are also testing participatory governance through DTs, such as Herrenberg (Germany), where citizens participated in information sessions about the DT and reported positive feedback on the initiative (Dembski et al., 2020). These examples show that UDTs are not confined to back-end resource management: when designed with citizens in mind, they can also serve as channels through which residents are informed about, or consulted on, decisions affecting their city. This raises the question of how far that channel can go – whether citizens remain recipients of information and consultation, or whether the UDT can be reshaped by them into something closer to a tool of self-government. The democratic potential of UDTs lies not merely in enabling access or consultation, but in their capacity to be *hackable*: open systems that can be reconfigured to expand, rather than restrict, the range of political choices (Micciarelli, 2024). This extends the inclusivity argument developed by Coluccino et al. (2025), which frames UDTs as socio-technical infrastructures that require explicit inclusion by design.

Rather than serving as forecasting tools that guide data-driven policy for decision-makers, UDTs can act as prefigurative infrastructures where alternative scenarios are tested and debated. Realizing this potential, however, requires directly confronting persistent inequalities in digital access and literacy that risk undermining the democratizing promise if not proactively addressed (Ragnedda and Ruiu, 2020). Whether the EU's legal and policy framework imposes such proactive action is the question we turn to next.

3. Urban Digital Twins in the EU Policy Framework

The EU's policy landscape aligns data-driven innovation with inclusion goals through the European Strategy for Data (COM(2020) 66), the European Green Deal (COM(2019) 640), and the 2030 Digital Compass (COM(2021) 118). Binding instruments, such as the GDPR (2016), the DGA (2022), the European Accessibility Act (EAA)[4] (2019), and the AIA (2024), establish guardrails for privacy, data sharing, accessibility, and algorithmic risk. Taken together, however, these instruments do not establish a general, enforceable UDT-specific duty for municipalities to undertake participatory co-design or provide the capacity-building needed for effective participation. The AIA provides partial procedural hooks where a UDT component qualifies as a high-risk AI system, including provider-side risk management under Article 9 and, for relevant public-sector deployments, the fundamental-rights impact assessment under Article 27. Although the GDPR requires controllers, where appropriate within a data protection impact assessment, to seek the views of data subjects or their representatives, this limited procedural requirement does not amount to a general duty of participatory co-design or targeted engagement with underserved groups; nor does the DGA impose such a duty for UDTs. The result is a predominantly compliance-oriented framework in which applicable safeguards may be satisfied without actively embedding marginalised voices in the UDT modelling loop - a gap that can channel benefits towards already well-served publics and reproduce digital divides (Garske et al., 2024). Moving from this compliance baseline towards active inclusion requires participation standards, intersectional inclusion metrics,

[4] Directive (EU) 2019/882 (EAA). European Accessibility Act.

and funding conditions tied to demonstrable co-creation, outreach and digital-literacy support (Garske et al., 2024; Zygmuntowski et al., 2021; Eurocities, 2024; READJUST Consortium, 2024). The next section unpacks what this shift from compliance to active inclusion actually entails.

4. Beyond Legal Compliance: The Ethical Stance of UDTs

Legal compliance and active inclusion constitute distinct but overlapping dimensions of UDT governance. Legal compliance concerns satisfaction of the applicable obligations, including privacy, accessibility and non-discrimination requirements, whereas active inclusion concerns whether the design and governance of the UDT effectively enable marginalised groups to participate in decision-making and policy design. Indeed, active engagement fosters a sense of agency and enhances community responsiveness (Qanazi et al., 2025), acting as a starting point towards the engagement of marginalised individuals and communities. If a UDT is built without actively enabling these voices, it risks misrepresenting the community it aims to reflect, reinforcing social invisibility in urban policy analysis.

This distinction has direct design consequences that structure the analysis in Section 6. Compliance-oriented safeguards are principally relevant to the enabling and protective conditions reflected at the lower levels of the Digital Citizenship Rainbow (Net, Access, Services), — introduced in full in Section 5.1 — although the Rainbow does not itself measure legal compliance. Active inclusion is most clearly tested at the upper levels of Consultation and Democracy, where formal participatory opportunities require institutional investment in facilitation, outreach and capacity-building to become effective. The civic technologies analysed here often perform well on protective dimensions while systematically underinvesting in active-inclusion mechanisms – a structural gap that UDT developers must explicitly plan to close.

Against this backdrop, the concept of "hackability" – namely, the capacity for citizens to reconfigure socio-technical systems beyond their original design parameters – also carries direct design implications (Micciarelli, 2024)[5]. Where legal compliance establishes safeguards and active inclusion enables effective participation, hackability positions citizens as co-authors of the system, capable of testing alternatives and expanding political choices rather than accepting those pre-filtered by expert models (Castells, 2015). For UDTs, we defend that this entails open APIs, interoperable data standards, and modular architectures that allow civic actors to extend and contest the DT rather than merely consume it. Yet none of this is meaningful if certain individuals or groups cannot reach that point of engagement in the first place — a question of vulnerability we address in the next section.

5. Vulnerability Framework for Urban Digital Twins

5.1 Conceptualizing Vulnerability in Digital Citizenship Contexts

In UDT design, platform layout may be among the primary "hazard sources". Indeed, a poor platform interface may result in exclusionary effects, disproportionately impacting populations with possibly intersecting vulnerability characteristics, such as the elderly and those with low digital literacy.

Following Cardona et al. (2012), vulnerability can be understood as the set of attributes or circumstances that makes exposed elements susceptible to adverse effects when they impact the hazard source. Luna (2009)'s "layers not labels" approach, according to which vulnerability dimensions are not fixed attributes but dynamic constructs shaped by status, time, and location, shifts the analytical focus from fixed individual attributes to relational and contextual conditions of vulnerability. Combining the two approaches allows for repositioning poor design, rather than the individual, as the locus of risk. Legal and philosophical perspectives reinforce this relational understanding, stressing that vulnerability is shaped by institutional settings and legal frameworks (Zanetti, 2019; Zullo, 2020; Pastore, 2022; Galli and Novelli, 2024) – which means vulnerability audits cannot rely on static checklists but must track how the same person moves between states of inclusion and exclusion across platform contexts, where inclusion and exclusion are treated as spectra capable of capturing complexity, rather than rigid binary states.

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[5] Following Micciarelli (2024), we conceptualize hackability as requiring two jointly necessary conditions: a technical affordance (modifiable interfaces or data structures) and a governance affordance (rules recognising citizen-initiated changes as legitimate). This distinguishes hackability from openness (access and transparency: can the system be seen?) and interoperability (data exchange between systems: can systems talk to each other?); neither entails that citizens can reshape the system itself, though both are usually preconditions for it.

These frameworks need to be integrated because each contributes a distinct piece to the complex concept of vulnerability. Luna's approach addresses the "ontological question"—namely "what is vulnerability?" – by treating it as a relational, dynamic condition rather than a fixed attribute. We borrow Cardona's disaster risk vocabulary of "hazard" and "exposure" to answer the "structural question": how does a design artifact become a source of harm ?

We complement this approach by also adopting the "Rainbow of Digital Citizenship" (DCR) (De Cindio & Trentini, 2024), which answers the "operational question": at which point in the participation process does exclusion materialise, and what would meaningful inclusion look like at that point? De Cindio and Trentini explicitly built their framework on Arnstein's (1969) ladder of citizen participation, transposing it to the architecture of digital services. This genealogy matters for our purposes: like Luna's vulnerability, Arnstein's ladder rejects a binary of "included" and "excluded", treating participation instead as a gradient of decision-making power – from manipulation and tokenism to genuine citizen control.. The DCR inherits this logic and operationalises it for digital contexts, identifying at which level each digital civic infrastructure operates within this hierarchy, and consequently where exclusion is likely to materialise.

Therefore, our framework comprises both:

a. the vulnerability assessment (Sections 5.2–5.3) which operates as a diagnostic tool, identifying at-risk individuals and populations,

b. the DCR, which-by inheriting from Arnstein's ladder the idea that participation is a matter of degree rather than a binary state-maps where, along that same gradient, risks are most likely to materialise.

5.2 Five Vulnerability Dimensions in UDT Contexts

Without any pretense to exhaustively cover every dimension of vulnerability, we consider five axes that empirical research on digital inequality (Ragnedda and Ruiu, 2020; van Dijk, 2020) has found systematically susceptible to UDT design failures on the basis of recognised accessibility assessments, namely:

- Digital literacy barriers, such as ignorance about how to navigate the internet and exploit its services, resulting in users experiencing the digital divide (Ragnedda and Ruiu, 2020). Approximately 44% of Europeans lack basic digital skills (Eurostat, 2023), a figure that maps directly onto the population at risk of being unable to use UDT-based consultation tools regardless of their formal availability .

As for any vulnerability dimension, low digital literacy may intersect with other axes, giving rise to more complex patterns of vulnerability. The "grey divide" represents the most documented one, where age intersects with economic disadvantage to compound exclusion (Friemel, 2016; Van Dijk and Van Deursen, 2014). Moreover, it is worth mentioning that formerly incarcerated individuals face further compounded barriers, given that systematic exclusion from digital technologies during incarceration creating a distinctive, time-bound form of vulnerability. (Reisdorf and Rikard, 2018);

- Structural accessibility barriers. Interfaces that lack screen-reader compatibility, adjustable font sizes, or keyboard navigation make UDT consultation tools harder, or impossible, for disabled and older users to access.

Disability-related digital exclusion demonstrates stark quantitative patterns: UK data show that disabled adults are substantially more likely to be internet non-users than non-disabled adults (ONS, 2021). The 2024 WebAIM analysis found 95.9% of home pages contain detectable Web Content Accessibility Guidelines (WCAG) failures, averaging 56.8 errors per page-a figure that translates directly into legally actionable harm, with over 4,000 Americans with Disabilities Act-related lawsuits filed in 2024 alone (WebAIM, 2024; UsableNet, 2025). While these figures concern websites in general rather than UDTs specifically, the dashboards and consultation modules through which UDTs expose participation opportunities are themselves WCAG-governed web interfaces, making this evidence analytically transferable to UDT consultation interfaces, which are themselves web-based and WCAG-governed. This literature distinguishes five disability categories relevant to interface design, namely: visual, hearing, motor, cognitive/learning and speech impairments. Each of them requires distinct accommodations (Dobransky and Hargittai, 2006; Johansson et al., 2021);

- Socioeconomic stratification. Economic barriers create several distinct obstacles to meaningful UDT access that go beyond simple device ownership: capped or pay-as-you-go data plans discourage sustained engagement with data-intensive visualisation and simulation tools; households sharing a single device face practical limits on who can participate, and when; and reliance on another person's device or account (proxy dependence) constrains the privacy and autonomy needed for genuine participation (Ragnedda et al., 2022). Across the EU, rural household internet access stands at 91% versus 95% in cities (Eurostat, 2024), – a gap small enough at the

connectivity level, but one that compounds with the lower bandwidth typical of rural areas (European Commission, 2023), which strains the data-heavy 3D visualisations and live simulation layers that distinguish UDT interfaces from ordinary municipal websites;
- Legal status and documentation barriers, since requirements for state-issued identity documents can create de facto barriers for undocumented migrants, asylum seekers, and people between residency statuses, such as those awaiting a renewed permit or pending asylum decisions (Matlin et al., 2025; Malgieri, 2020). Homeless adults face a similar obstacle, as identity verification and proof-of-address requirements common to participation platforms presuppose a stable residential address they do not have. Minors raise a distinct and more delicate issue: GDPR Art. 8 requires parental consent before processing their data in information society services, a safeguard that exists precisely to protect their legal incapacity, privacy, and welfare, not an arbitrary barrier to be removed. The design challenge is therefore not to bypass this protection but to build consent flows that are genuinely workable for minors and their guardians, so that the safeguard does not collapse into a de facto exclusion from civic participation (Malgieri and Rebrean, 2024);

- Identity and expression safety, as vulnerability in UDTs may also be shaped by sexual orientation, gender identity and expression, religious affiliation, and cultural background. Indeed, the EU Agency for Fundamental Rights' LGBTIQ survey documents persistent concealment, self-censorship, and avoidance among LGBTQIA+ people in both online platforms and face-to-face civic settings (FRA, 2024). Similarly, while direct empirical evidence in UDT contexts remains limited, analogous dynamics have been documented in broader platform governance literature: individuals belonging to minority religious communities or culturally marginalized groups are likely to face hostile online environments, underrepresentation in platform moderation norms (i.e., moderation rules rarely shaped by minority input), and content standards that reflect dominant cultural assumptions rather than pluralistic urban realities (FRA, 2024; Haimson and Hoffmann, 2016). "Real-name" and authenticity policies systematically disadvantage non-normative identities across all these axes, producing chilling effects and strategic identity masking. Within UDTs, these dynamics translate into lower participation relative to otherwise comparable users who are not navigating these identity risks, selective data sharing, and silent drop-off from deliberative tools even where interface accessibility is formally adequate.

5.3 Intersectional Impact Patterns

Empirical research confirms that these dimensions interact to produce compound exclusion exceeding additive models (see Figure 1). Norwegian registry data show that women with disabilities face income gaps larger than those associated with either axis alone (Ballo, 2023), illustrating how economic disadvantage compounds into reduced device access and UDT participation. Large-scale analysis (n = 19.5 million) documents how disability, gender, race-ethnicity, and age combine to create disadvantage patterns invisible to single-axis analysis (Bixby, 2024). European-wide multilevel analysis across 27 countries confirms that financial constraint, aging, and isolation create particularly severe digital exclusion when combined with disability status (Scholz et al., 2017). These patterns suggest that design barriers are unlikely to behave additively—disadvantage compounds at intersections. Applied to UDTs, this implies that compliance with individual accessibility requirements may still fall short of active inclusion: platforms must be stress-tested against combined vulnerability profiles rather than individual characteristics in isolation.
The combination shown in par. 5.2 is applied in Section 6 through two related questions: whether each platform provides compliance-relevant protective conditions and whether it actively enables persons exposed to the identified vulnerability dimensions to participate and exercise meaningful influence.

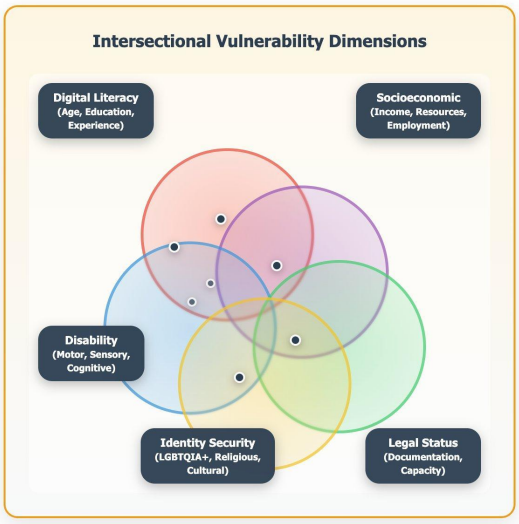


Figure 1. Intersectional Vulnerability Dimensions in Digital Citizenship. Own elaboration.

6. Platform Patterns: Inclusivity and Vulnerability in Practice

Moving from the conceptual analysis of vulnerability, we analyse six digital civic infrastructures – FixMyStreet, Ushahidi, Decidim, DestinE, PartecipaMi, and FAST-LISA – grouped by type, from low-tech civic reporting through open-source and municipal participation to high-complexity EU scientific twinning, with FAST-LISA last as a design model rather than a deployed platform. They were selected to maximise contrast across DCR tiers coverage, deployment scale and institutional context, and are analysed through the distinction between compliance-relevant protective features and active inclusion. The analysis remains interpretive and illustrative rather than statistically representative.

- FixMyStreet, a UK platform launched by mySociety in 2007 that lets residents report local infrastructure issues, operates at Services and Transparency levels, offering transparent accountability chains between residents and local authorities. Yet a study of 30,041 Brussels reports found strong socio-demographic biases-lower use in the poorer districts most in need of repair (Pak et al., 2017). Technical optimisation uncoupled from equity mechanisms is a distributional choice, not a neutral one.
- Ushahidi**,** a crisis-mapping platform born in Kenya in 2008 and now used worldwide, operates at the Access and Services levels that accepts reports via SMS, USSD, email, and web forms, substantially lowering access thresholds for populations with limited connectivity (Goodchild and Glennon, 2010). However, lowering barriers on the socioeconomic axis leaves disability accessibility largely unaddressed-illustrating how vulnerability dimensions intersect rather than add.
- Decidim is the most ambitious open-source participatory democracy platform, covering Transparency, Consultation, and Democracy in DCR terms, with Barcelona's participatory budgeting involving tens of thousands of residents (Participedia, 2020). Its "technopolitical" architecture provides auditable decision chains resistant to unilateral alteration (Barandiaran et al., 2024). Analysis of its discussion threads further shows that the platform's hybrid interface, which combines conversation threading with explicit positive/negative alignment markers, is more effective at triggering deliberative exchange around contested proposals than simpler petition-style designs (Aragón et al., 2017). Yet its richness can inadvertently create barriers: without facilitation, training, and institutional investment there is a risk of elite capture that reproduces digital literacy and socioeconomic inequalities (Suter, 2024).
- DestinE (Destination Earth) exemplifies the accessibility paradox.An EU-funded digital twin of the Earth developed by ESA, EUMETSAT and ECMWF, it sits at the Access and Services levels of the DCR. Its urban modules-including CityNexus, which enables "what-if" scenario simulations for cities such as Bologna, and an Urban Heat Health Forecasting service targeting public health managers-demonstrate genuine technical sophistication (DestinE Project, 2024a, 2024b). Yet its tiered access model and technically demanding interfaces mean that despite formally open registration, meaningful use still presupposes advanced digital literacy. Without mediation by civic organisations or local authorities, most vulnerable groups remain structurally excluded.
- PartecipaMi (Milan, 2008) is the City of Milan's civic-participation platform, active at the Services, Transparency and Consultation levels; itdemonstrates inclusivity as situated practice through its collaborative

mapping of accessible parking spaces for people with disabilities (Comune di Milano, 2023). It has sustained a continuous user community for over fifteen years, though limited outreach prevents targeted successes from scaling to systemic inclusion.

- FAST-LISA, an European project and e-participation platform is included not as a deployed urban platform but as a design model operating at the Education level of the DCR: its multilingual hate-speech classifier and reflexive dashboard allow citizens to self-assess discourse risks before engaging in civic deliberation (Palmirani et al., 2023). The lesson for UDTs is that participatory spaces benefit from embedded protective infrastructure at the Education level of the Rainbow-reducing harm exposure as a precondition for democratic participation.

Table 1. Platform alignment with Digital Citizenship Rainbow levels (✓ = strong; (◦) = partial)

Platform	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
FixMyStreet	✓	✓		✓	✓	(◦)		
Ushahidi	✓	✓	✓	✓	(◦)	(◦)		
Decidim		✓		✓	✓	✓	✓	✓
DestinE		(◦)		✓	✓			
PartecipaMi	✓	✓		✓	✓	✓	(◦)	
FAST-LISA			✓				(◦)	(◦)

Levels: 0 The Net | 1 Access | 2 Education | 3 Services | 4 Transparency | 5 Sharing | 6 Consultation | 7 Democracy

Table 1 shows that no platform spans all DCR levels, and that no single platform spans all Rainbow levels and that compliance-relevant protective features or broader Rainbow coverage do not automatically translate into active inclusion or higher democratic quality. These results converge on four cross-cutting lessons for UDT governance: (1) Efficiency-equity trade-off: technical optimisation uncoupled from outreach is a distributional choice – UDTs must complement data-driven efficiency with targeted mechanisms to prevent the modelling loop from underweighting marginalised neighbourhoods. (2) Multi-channel access is necessary but not sufficient: lowering socioeconomic barriers does not automatically address disability accessibility; multi-channel design is one layer in a wider stack. (3) Democratic richness creates elite-capture risk: without facilitation, training, and institutional support, participation skews toward digitally skilled citizens (Suter, 2024); governance ecosystems must be planned as integral components. (4) Technologic sophistication and democratic accessibility can be in structural tension: DestinE shows that open registration is insufficient when interfaces presuppose expert literacy.

Taken together, Sections 4 through 6 have shown that legal compliance, however necessary, is not sufficient for active inclusion: the ethical case for hackability (Section 4) identifies what genuine citizen co-authorship would require; the vulnerability framework (Section 5) specifies who is at risk of being excluded from it and why; and the platform analysis (Section 6) confirms that even well-designed civic infrastructures rarely close this gap on their own. The following section translates these findings into policies and new research directions.

7. Research and Policy Implications

7.1 Policy Directions

At the regulatory level, all EU-funded UDT initiatives should undergo two complementary assessments: a module-specific legal-compliance review and an intersectional active-inclusion audit testing actual usability, representation and influence across combined vulnerability profiles, with both incorporated into funding conditions (Verdegem, 2011; Eurocities, 2024; READJUST Consortium, 2024; Garske et al., 2024). We argue that the European Data Act[6] (DA), the DGA, and AIA delegated regulations should, where legally feasible, include participation standards requiring demonstrable co-design with underserved groups, alongside

[6] Regulation (EU) 2023/2854 (DA). Data Act.

intersectional accessibility auditing and capacity-building conditions for funding (Lopez Solano et al., 2022). Participatory rights should not be limited to legal residency alone; municipalities should explore inclusion models that also accommodate commuters, undocumented individuals, and other precarious urban populations (Mesure and Branlat, 2024).

7.2 Technical and Procurement Priorities

At the infrastructural level, comprehensive digital literacy programmes targeting the 44% of Europeans lacking basic digital skills are a prerequisite for meaningful UDT participation (Eurostat, 2023), with specific provision for older adults, migrants, formerly incarcerated individuals, and other groups facing temporal or structural literacy gaps. Device lending, multilingual support, and hands-on UDT familiarization at community hubs should be funded as complementary infrastructure, not optional add-ons. At the platform level, multi-modal accessibility architecture addressing all five disability categories identified in Section 5.2, progressive interface complexity adapted to user competence levels, and tiered authentication systems requiring robust verification only for high-stakes binding decisions can substantially reduce structural barriers (Fung, 2006).

At the most demanding level of active inclusion, these measures must be complemented by an open architecture that enables civic actors to scrutinise, extend and contest the UDT. Hackability, as the capacity for civic actors to extend, contest, and reimagine the UDT beyond its original design, is hardly achievable on closed proprietary systems. Concretely, this translates into three technical requirements: (1) open APIs that allow third-party civic organizations and researchers to build accessible interfaces and alternative visualizations on top of the core twin data; (2) interoperable data standards that prevent platform lock-in and enable cross-city comparison and oversight; and (3) modular architectures that allow components-including participation modules, data layers, and visualization interfaces-to be replaced or augmented by community actors without requiring access to the full system. These requirements should be treated as procurement conditions in EU-funded UDT initiatives, not as aspirational design preferences. Longitudinal research tracking how vulnerability patterns shift as platforms evolve remains a significant gap; such studies would enable more responsive and adaptive UDT designs and help distinguish persistent structural barriers from transitional implementation challenges.

7.3 Limitations and Future Research

The proposed framework is intended as a conceptual and diagnostic tool, rather than as a validated measurement or scoring system. The five vulnerability dimensions identify key forms of exclusion without claiming to provide an exhaustive account of vulnerability in UDT contexts. The six platform cases were selected purposively to maximise contrast across functions, institutional settings and participatory models, rather than to provide a statistically representative sample; together with the predominantly European focus and reliance on secondary sources and platform documentation, this limits the generalisability of the findings and prevents direct assessment of user experiences across the identified vulnerability dimensions. The framework is also not yet operationalised through validated indicators, weights or scoring thresholds: this is a deliberate boundary of the present contribution, which establishes the conceptual dimensions and evaluative logic on which such measures can be designed, while their development and validation are being pursued in ongoing investigations on platforms. Future research should test and refine these measures through participatory audits, primary usability and accessibility assessment, longitudinal analysis and comparative application across different UDT contexts, while also examining the trade-offs generated by active inclusion, including tensions between broader participation, administrative cost/benefits, security, privacy, representativeness and technical feasibility.

8. Conclusions

This paper has examined vulnerability and digital citizenship in UDTs through the distinction between legal compliance and active inclusion. Section 3's legal analysis established that EU instruments - namely the GDPR, the DGA, and the AIA - provide a compliance floor without mandating co-design with underserved groups, motivating our reframing of poor platform design itself as a hazard source. Building on this, in Section 5 we adapted disaster risk assessment methodologies - through Cardona's (2012) hazard/exposure vocabulary and Luna's (2009) "layers not labels" approach, combined with De Cindio and Trentini's (2024) DCR - to identify five intersecting vulnerability dimensions whose compound effects exceed additive predictions (Bowleg, 2008). The platform evaluation in Section 6 tried to exemplify this claim: no civic technology we analyzed spans the full DCR, and richer platforms can paradoxically raise barriers absent facilitation. These diagnostic findings ground the governance recommendations of Section 7 – binding participation standards, intersectional

accessibility audits, and open-architecture requirements – which translate the vulnerability framework into concrete design and procurement conditions.

Together, these four strands substantiate our central claim: UDTs as tools for democratic governance depend not only on computational sophistication and legal compliance, but also on their capacity to secure the active inclusion of diverse urban inhabitants. Each strand answers a question the others leave open: what compliance omits, where exclusion materialises, and what remedies it demands. As argued in Section 4, passive measures – privacy safeguards, anti-discrimination provisions – shield citizens from harm but leave them recipients of design choices made elsewhere. Only active measures – facilitation, outreach, capacity-building – and hackable, contestable architectures give marginalised groups genuine standing as co-authors of the systems governing their cities. By combining legal safeguards with intersectional vulnerability assessment and active-inclusion practices, cities can significantly reduce the risk that the digital infrastructures of tomorrow deepen - rather than bridge - the divides of today.

Use of generative AI: The authors used Claude Sonnet 4.6 and 5.0 (Anthropic) in a supportive capacity during the preparation of this contribution, including language editing, length reduction, and internal consistency checks. The tool was not used to generate data, findings, or analysis; all interpretations and conclusions remain the sole responsibility of the authors.

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