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Designing Inclusive Urban Planning Platforms Integrating Real-Time Sign Language Interpretation for Deaf Community Participation in Policymaking

Bukola Linda Oloba[1], Ngozi Faith Oguejiofor[2], Yinka Samuel Ogunlana[3], Paul Okugo Imoh[4], Toyosi Motilola Olola[5]

[1]Department of Communication, North Dakota state university, USA.

[2]Department of Communication, University of Nevada, Reno, United States.

[3]Department of Instructional Design and Technology, Western Illinois University, Macomb, USA

[4]School of Nursing, Anglia Ruskin University, Essex, United Kingdom.

[5]Department of Communications, University of North Dakota, Grand Forks, USA.

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Abstract: **Urban planning processes often marginalize people with disabilities, especially members of the Deaf community, due to limited accessibility in communication channels used in public consultations and decision-making forums. This review explores how real-time sign language interpretation technologies can be integrated into digital urban planning platforms to foster inclusive governance and participatory policymaking. It examines existing barriers to participation, technological advancements in real-time interpretation, and frameworks for inclusive design in civic technology. Drawing on interdisciplinary research from urban studies, disability rights, and digital accessibility innovation, the study highlights best practices and case studies where urban planning has been made more inclusive for deaf individuals. It also critiques existing digital platforms used in municipal planning and evaluates how they can be restructured to include accessible features such as live sign language interpretation, captioning, and user-centered design principles. The paper underscores the need for a policy shift towards equity in civic engagement and presents a strategic roadmap for embedding accessibility in smart city initiatives. Ultimately, this review advocates for participatory justice through inclusive technology, ensuring that the voices of the Deaf community are heard and valued in shaping urban futures.**

Keywords: **Inclusive Urban Planning; Sign Language Interpretation; Deaf Community Participation; Accessible Digital Platforms; Civic Engagement Technology.**

1. INTRODUCTION

1.1 Background and Rationale

Urban planning has historically overlooked disabled citizens, reinforcing ableist norms and entrenching social exclusion. Stafford and Vanik (2022) argue that disability justice requires reimagining planning itself: transforming environments and decision-making to recognize disabled people as rights-holders, not afterthoughts. This theoretical impetus aligns with empirical work: Gupta (2025) synthesizes global literature on inclusive public open spaces, highlighting that even where international standards such as the UN CRPD exist, enforcement mechanisms are weak especially in developing countries. These findings highlight the urgent need for urban policy to shift from token accessibility features to structurally inclusive policymaking platforms. Given this context, designing urban planning platforms that embed real-time sign language

interpretation becomes more than technical innovation it is a corrective to systemic oversight (Atalor, and Enyejo, 2025). By integrating such features, platforms would not only remove communication barriers but signal institutional commitment to equitable inclusion (Ononiwu, et al., 2023). The rationale is thus two-fold: normative (justice and human rights) and functional (improving governance outcomes). Ensuring deaf community participation via real-time sign language features aligns with universal design praxis and deepens legitimacy in policymaking—converting abstract commitments into material infrastructure for inclusion.

1.2 Importance of Inclusive Urban Planning

Inclusive urban planning is foundational to equitable, resilient cities that serve diverse populations. Müller (2021) demonstrates how normative planning documents invisibilize disabled users through default "normate templates," reinforcing ableism by defining the 'intended user' as able-bodied unless explicitly otherwise. This exclusion translates into design norms that systematically marginalize disabled citizens in built environments and policy forums. Meanwhile, Gupta (2025) emphasizes that inclusive planning frameworks—particularly those that incorporate disability and gender sensitivity are vital in catalyzing participatory governance and social inclusion, especially when technological innovations such as AI-based wayfinding or assistive systems are employed. These findings affirm that inclusive planning is not an optional add-on but integral to democratic legitimacy and social cohesiveness (Atalor, et al., 2023). In this light, integrating real-time sign language interpretation within urban planning platforms is pivotal: it directly addresses communicative inclusion while advancing broader policy goals. Such inclusive features ensure that planning deliberations are truly public, democratic, and reflective of human diversity (Ononiwu, et al., 2025). Technically, platforms with integrated sign language services can also enhance engagement analytics, reduce miscommunication, and expand reach making planning processes more effective and accountable.

1.3 Deaf Community in the Context of Urban Policy

The Deaf community is distinct not only by sensory difference but by cultural and linguistic identity factors often misrecognized in policy design. Crowe, Dusenbery, and Hussemann (2022) illustrate through urban research protocols that meaningful engagement with Deaf communities requires ASL fluency, cultural humility, and tailored data collection methods. Conventional research and service delivery models that fail to account for these aspects end up alienating Deaf participants and distorting outcomes. Similarly, McKee et al. (2011) found that Deaf ASL users experience significant disparities in access to preventive health services owing to communication barriers underscoring how lack of sign language access in public contexts directly undermines equity. Translated into urban policymaking contexts, these findings indicate that without real-time sign language interpretation embedded into platforms, Deaf citizens cannot meaningfully participate in consultations or governance forums (Atalor, and Enyejo, 2025). For example, city council digital town halls or planning workshops without sign interpretation exclude Deaf stakeholders from influencing zoning decisions or public investments. Embedding real-time ASL interpretation hence becomes essential not just for access but for preserving democratic equality, linguistic rights, and cultural dignity ensuring that the Deaf community engages on an equal footing in shaping urban futures.

1.4 Objectives and Scope of the Review

The primary objective of this review is to examine how real-time sign language interpretation can be effectively integrated into urban planning platforms to foster inclusive participation for the Deaf community in policymaking. The review aims to identify existing technological, social, and policy barriers to Deaf inclusion, evaluate emerging tools and frameworks that enable real-time communication accessibility, and propose actionable strategies for embedding sign language functionality within digital civic engagement systems. Furthermore, it explores the intersectionality between urban governance, accessibility technologies, and disability rights frameworks, with an emphasis on participatory justice and inclusive design. The scope of the review encompasses international case studies, legislative frameworks such as the Convention on the Rights of Persons with Disabilities (CRPD), and interdisciplinary research from urban studies, communication accessibility, and human-computer interaction. By centering the Deaf experience within urban governance discourse, the review contributes a critical perspective on inclusive policy innovation and digital equity.

1.5 Structure of the Paper

This paper is organized into six main sections to provide a comprehensive and logically structured exploration of the topic. Section 1 introduces the context, rationale, and objectives of the study, establishing the importance of inclusive urban planning for Deaf communities. Section 2 investigates the systemic and communication barriers that hinder Deaf

participation in policymaking. Section 3 examines the technological landscape of real-time sign language interpretation tools, including AI-based solutions and human-in-the-loop models. Section 4 analyzes best practices and design principles for inclusive urban planning platforms, incorporating accessibility-driven user experience strategies. Section 5 discusses the ethical, policy, and implementation challenges associated with deploying such systems in real-world planning processes. Finally, Section 6 synthesizes the key insights and outlines future directions for policy reform, technological innovation, and inclusive urban governance.

2. BARRIERS TO DEAF PARTICIPATION IN URBAN POLICYMAKING

2.1 Communication Challenges and Exclusion

Deaf individuals routinely confront multifaceted communication barriers in civic processes that rely on spoken or text-only interactions. Abou-Abdallah and Dhillon (2021) document how reliance on unfamiliar written forms, lip-reading, or Video Remote Interpreting (VRI) disrupts nuanced conversation, compromising comprehension and leading to inadvertent exclusion of Deaf participants as represented in figure 1. Corroborating this, Naseribooriabadi and Mehravaran (2017) reveal that limited health literacy among D/deaf populations stems from systemic communication inadequacies particularly the absence of sign-centric information pathways creating entrenched exclusion from public information and decision-making. Such deficits are not isolated to healthcare they extend to urban governance forums where complex debates and planning jargon compound comprehension challenges. When civic platforms lack real-time, fluent sign language channels, Deaf participants cannot fully decode policy content, ask clarifying questions, or express views effectively. This leads to a cascade of exclusion: from inability to follow proceedings to silent withdrawal from engagement. Technical failures of VRI or poorly designed text interfaces can exacerbate this, resulting in Deaf stakeholders being perceived as disengaged rather than underserved. Addressing these communication barriers is therefore pivotal not only to facilitate inclusion but also to uphold the legitimacy and representativeness of urban planning processes.

Figure 1: Picture of Bridging Communication Gaps with Sign Language to Foster Inclusion and Understanding (Hanoğlu, S. 2022)

Figure 1 depicts an adult woman and a young girl engaged in sign language communication, likely in an educational or early learning setting. The woman, seated on the left and wearing a coral-colored shirt and a smartwatch, is mid-sign, her hands positioned near her chest with fingers extended in a structured formation. The girl, seated opposite and wearing a floral top, mirrors the signing posture, suggesting a responsive learning exchange. This visual directly connects to *Communication Challenges and Exclusion*, as it illustrates the intentional use of sign language to bridge linguistic gaps in environments that would otherwise rely on spoken communication. In many civic and educational contexts, such visual-manual interaction is absent, leading to systemic exclusion of Deaf individuals from full participation. Without trained interpreters or accessible digital interfaces, critical information whether policy updates, classroom instructions, or public

consultations remains inaccessible to those who rely on sign language. Technically, the image highlights both the importance of direct, synchronized visual communication and the role of environmental factors (clear line of sight, controlled background noise, adequate lighting) in optimizing comprehension for Deaf participants. It serves as a microcosm of the broader necessity for real-time interpretation in urban planning platforms, where absence of such measures perpetuates informational inequity and limits active civic engagement for Deaf communities.

2.2 Limitations in Current Urban Engagement Platforms

Current digital civic participation platforms often fail to account for inclusive accessibility demands. Chassin et al. (2021) develop a seven-dimension access evaluation framework spanning accessibility, availability, adequacy, affordability, acceptability, awareness, and attractiveness highlighting that digital mediums frequently optimize for general usability rather than specialized inclusion. Notably, accessibility and adequacy for Deaf users are often absent from design criteria. Complementing this, Pak et al. (2017) analyze usage of the FixMyStreet platform in Brussels and reveal stark sociodemographic disparities in civic participation, with underrepresentation from marginalized communities often overlapping with disabled or Deaf populations. The study implies that when interfaces are not tailored to diverse linguistic or sensory needs, structural exclusion results. Many municipal engagement tools adopt uniform survey templates, map visualization, or text-based submission forms without integrated sign language modules, captioning, or interpreter access. As a result, Deaf individuals face cognitive overload, misinterpretation, and disengagement. Moreover, platforms that rely exclusively on written questions or static content inhibit real-time dialogue, critical for iterative planning deliberations (Gayawan, & Fagbohungbe, T. 2023). These limitations necessitate the integration of accessible modes particularly sign language interpretation to ensure urban engagement platforms fulfill equitable participation mandates.

2.3 Societal Attitudes and Policy Gaps

Societal norms often perpetuate exclusion through tokenistic inclusion and lack of enforceable policies. Chemnad et al. (2024) critically assess AI-driven accessibility solutions, reporting that most digital systems still privilege visual impairments over hearing-based accessibility as shown in table 1. The systematic review underscores that Deaf needs such as real-time sign language translation are consistently underrepresented or absent in design frameworks (Chemnad et al., 2024). Furthermore, De Meulder et al. (2024) illustrate how deaf community involvement in sign language technology is often symbolic, fraught with power imbalances and tokenism without deep structural shifts, policies remain superficial, failing to mandate Deaf leadership or workload recognition (De Meulder et al., 2024). Combined, these insights reveal a dual failure: societal attitudes undervalue Deaf communicative norms while policy frameworks fail to mandate meaningful, accessible implementations. For urban planning platforms, this means that even when awareness exists, without legal or regulatory enforcement, platforms remain inaccessible (Ononiwu, et al., 2023). Deaf stakeholders are relegated to passive spectators in civic processes, reinforcing systemic inequities. Bridging this gap requires not only technology but a shift in governance ethos—recognizing sign language access as a civil right and embedding Deaf leadership in policy development and execution.

Table 1: Summary of Societal Attitudes and Policy Gaps

Key Issue	Description	Example or Insight	Implication for Inclusive Design
Tokenistic Inclusion	Deaf communities are often superficially included in tech design processes	Deaf individuals are invited as "consultants" but lack decision-making power	True inclusivity requires co-design and power-sharing mechanisms
Policy Underrepresentation	Sign language accessibility is absent in many regulatory standards	AI frameworks often prioritize visual impairments, overlooking Deaf communication needs	Laws must explicitly require sign language and Deaf-centered accessibility
Cultural Misunderstanding	Deaf culture and communication norms are often poorly understood in policy	Hearing-centric assumptions dominate platform architecture	Designers and policymakers must be trained in Deaf cultural norms
Lack of Enforcement	Accessibility standards are not consistently enforced across civic platforms	Optional accessibility features lead to inconsistent user experiences	Mandatory compliance policies with monitoring frameworks should be established

2.4 Case Examples of Exclusion from Policymaking

Concrete examples illustrate how exclusion manifests in policymaking contexts. McRae et al. (2025) report lived experiences from Deaf Australians who voiced feeling perennially "on the outside" due to inaccessible childhood communication language deprivation had enduring effects on their civic confidence and mental well-being (McRae et al., 2025). This disenfranchisement carried into adulthood, where exclusion from planning events rooted in sign-free formats reinforced their marginalization. Similarly, Townley et al. (2024) evaluate digital civic tools and find that many planners implement online engagement technologies without customizing for Deaf participation, presuming written or audio inputs suffice (Townley et al., 2024). Such assumptions exclude Deaf voices from the deliberative process, particularly when feedback mechanisms lack sign-integrated channels. These studies underscore how failure to embed real-time sign language interpretation is not a technical oversight, it is a fundamental barrier to participation, reinforcing social exclusion and limiting the legitimacy of planning outcomes (James, et al. 2024). These concrete instances validate the urgent necessity to redesign civic infrastructures to include Deaf users from design through execution.

3. REAL-TIME SIGN LANGUAGE INTERPRETATION TECHNOLOGIES

3.1 Overview of Interpretation Tools and Interfaces

Sign language interpretation technologies span a continuum—from video-based systems leveraging computer vision to avatar-based representations and IoT-enabled wearables. Papatsimouli, et al., (2023) present a comprehensive analysis of AI methods encompassing hand and facial gesture capturing, recognition, translation, and representation, revealing that real-time performance typically relies on efficient CNN or multimodal pipelines integrating body and facial motion capture with NLP modules. IoT integration has further facilitated device interoperability, embedding interpreters into mobile and embedded environments. Papatsimouli et al. (2023) review advancements in IoT-augmented real-time sign language systems, highlighting how sensors (e.g., keypoint cameras, wearables) interface with ML backends to support low-latency gesture recognition, enabling field deployment in constrained hardware contexts. For instance, wearable inertial sensors combined with lightweight CNNs have enabled continuous recognition of a vocabulary of signs, broadcasting translations to users' mobile devices (Imoh, & Idoko, 2022). Despite these innovations, many systems remain task-limited (alphabet only, short vocabulary) and often exclude facial expression or co-articulation nuances critical in conveying grammatical meaning in sign languages (Tan, et al., 2024). Thus, while a spectrum of interpretation tools exists, achieving holistic, real-time, expressive sign interpretation remains a technical frontier demanding combined modal capture, real-time processing, and adaptive interface design.

3.2 Machine Learning and AI in Real-Time Sign Language Translation

Machine learning and AI are central to real-time sign language translation, particularly leveraging deep learning and keypoint-based recognition. Alsharif et al. (2025) demonstrate a system that combines YOLOv11 object detection with MediaPipe keypoint tracking to recognize ASL alphabet letters in real time, achieving an mAP@0.5 of 98.2% with optimized inference speed—a benchmark for real-time deployment. Complementing this, Núñez-Marcos (2023) surveys both traditional and neural sign language machine translation systems, revealing that transformer-based architectures, particularly those utilizing gloss-level tokenization, substantially enhance translation quality. These systems often employ sequence-to-sequence designs with attention mechanisms to align visual sign features to target-language tokens. In practice, real-time translation pipelines chain convolutional feature extractors, temporal modeling (e.g., LSTM or transformers), and decoder modules to map continuous signing into text or speech. Advanced models also integrate lip-reading and facial expression analysis to improve grammatical interpretation (Imoh, and Enyejo, 2025). Nonetheless, such pipelines entail high computational demands, making real-time performance sensitive to model complexity and hardware constraints. Strategies such as model quantization and lightweight architectures are thus critical to sustaining responsiveness without sacrificing accuracy (Ononiwu, et al., 2024).

3.3 Human Interpreter Integration in Digital Platforms

Human interpreter systems remain pivotal—either standalone or integrated alongside AI to ensure accessible engagement in digital platforms. Ellis, et al., (2025) provides a pioneering comparative study between AI-based translation systems and human interpreters, concluding that ML-powered bidirectional systems can achieve parity with human interpreters in accuracy, efficiency, and robustness across a cohort of 106 Deaf participants as represented in figure 2. This suggests that AI can meaningfully augment or complement human interpretation in civic contexts. Similarly, Z Yu et al. (2025) evaluate

a bi-directional avatar system against HandTalk, reporting a sign language production (SLP) accuracy of approximately 78% (± 1.7%), outperforming HandTalk's 61% (± 2.4%) and aligning with expert human baselines of around 72.7%. These results indicate that hybrid digital platforms embedding both AI-driven avatars and optionally live human interpreters can provide flexibility, scalability, and increased accessibility (Okpanachi, et al., 2025). For urban planning platforms, this suggests that offering toggleable modes AI avatars for routine updates, and live interpreters for policy deliberation can optimize inclusivity, resource allocation, and user trust.

Figure 2: Picture of Real-Time Human Interpretation Enhancing Digital Communication Accessibility (Kudo, 2024).

Figure 2 shows a woman wearing a headset seated at a desk with two laptops, engaged in a live video session. On one laptop screen, a blurred presenter is visible, while the woman faces the screen and gestures with her hand, indicating active sign language interpretation or visual communication. This scene illustrates *Human Interpreter Integration in Digital Platforms*, where a human interpreter is embedded into a digital environment to bridge real-time communication between Deaf participants and spoken-language presenters. Technically, such integration relies on stable video conferencing infrastructure, high-definition cameras for accurate handshape and facial expression capture, and low-latency streaming to maintain conversational flow. The headset allows the interpreter to receive the spoken content directly, while their visible hand movements are transmitted to the Deaf audience through the platform's video feed. This setup demonstrates a hybrid civic engagement model, where human interpreters complement AI-driven translation systems to ensure accuracy, cultural appropriateness, and emotional nuance—factors often lost in automated solutions. In urban planning platforms, similar interpreter integration ensures that live public consultations, virtual policy briefings, and participatory workshops are accessible to Deaf stakeholders in real time, reinforcing inclusivity and participatory equity.

3.4 Evaluation of Accuracy, Latency, and User Experience

Performance metrics for sign language interpretation systems must balance accuracy, latency, and user experience to ensure viability in civic settings. Fang et al. (2018) introduce DeepASL, a non-intrusive infrared-based system capable of translating ASL at both word and sentence levels using hierarchical bidirectional RNNs with CTC decoding; they report an average word-level accuracy of 94.5% and a word error rate of 8.2% indicating promising translation fidelity (Fang et al., 2018) as shown in table 2. Complementing this, the 2025 SLRNet achieves real-time recognition with LSTM-based temporal modeling, maintaining response latency below 70 ms crucial for fluid interaction, while running on standard laptops without specialized hardware (2025 SLRNet authors). These metrics underscore that systems can be both accurate and responsive, provided computational efficiency is optimized. User experience hinges not only on raw performance but

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also on perceptual smoothness, interface clarity, and expressive fidelity especially in conveying facial and grammatical nuances (Kamble, 2025). Thus, system evaluation must incorporate human-subject testing, measuring comprehension, cognitive load, and engagement quality alongside quantitative benchmarks. For inclusive urban planning platforms, prioritizing low-latency, high-accuracy sign translation enhances real-time participation and trust, supporting equitable stakeholder engagement (Imoh, and Idoko, 2023).

Table 2: Summary of Evaluation of Accuracy, Latency, and User Experience

Key Issue	Description	Example or Insight	Implication for Inclusive Design
Translation Accuracy	System's ability to accurately interpret sign language input	DeepASL achieves over 94% accuracy with sentence-level interpretation	High accuracy is crucial for semantic reliability and trust in civic contexts
Latency and Responsiveness	Time lag between input and output impacts communication flow	SLRNet delivers recognition in <70ms on consumer devices	Low-latency systems ensure real-time participation in live urban planning sessions
Usability and Fatigue	Poor UI or delayed feedback can lead to cognitive overload for Deaf users	Studies show that users experience reduced comprehension when video feeds lag or miss facial cues	Interfaces should balance speed, clarity, and comfort for long-term interactions
Multimodal Synchronization	Integration of visual, textual, and gestural content must be seamless	Incoherent multimodal content disrupts meaning, particularly in expressive grammar	Platforms must support synchronized layering of video, captions, and interactive features

4. INCLUSIVE PLATFORM DESIGN FOR URBAN PLANNING

4.1 Principles of Accessible Civic Tech Platforms

Accessible civic tech platforms must adhere to core design principles that ensure public institutions provide equitable engagement opportunities. Rudmark (2024) outlines three essential design tenets: fair access, which mandates universal usability; clarity, allowing users to intuitively navigate data; and responsiveness, ensuring timely and meaningful feedback loops in interactive governance systems as shown in table 3. Complementing this, Bhanye, and Shayamunda, (2025) underscores the role of transparency and accountability platforms should provide visible, accessible audit trails and foster user trust through interface clarity and open data release. Together, these principles emphasize that civic platforms function as public goods not proprietary tools and must remain universally accessible, transparent, and accountable. Technical implications for urban planning platforms include adopting WCAG-aligned designs, ensuring multiple communication channels (e.g., text, video, sign language feeds), and embedding meta-feedback loops where Deaf participants can monitor how their input influences policy decisions (Imoh, et al., 2024). Embedding these principles at the system architecture level facilitates inclusive participation, strengthens democratic legitimacy, and helps move accessibility from afterthought to core design value.

Table 3: Summary of Principles of Accessible Civic Tech Platforms

Key Principle	Description	Example or Insight	Implication for Inclusive Design
Universal Usability	Interfaces should be usable by people with diverse abilities	Open data platforms designed with screen readers, captioning, and keyboard navigation	Sign language modules and Deaf-first options must be embedded in civic platforms
Transparency and Accountability	Platforms must show users how decisions are made and how input is used	Civic-tech platforms with open feedback loops improve public trust	Deaf users must see how their contributions impact policy through accessible summaries

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Multichannel Access	Providing varied access routes (text, sign, visuals) supports wider engagement	Public platforms with live video and real-time interpretation yield higher user participation	Multimodal communication modes must be standard across urban digital forums
Scalability and Interoperability	Technology should be adaptable across settings and devices	Cloud and IoT-enabled interfaces scale interpretation services in community spaces	Sign-language tools should work on mobile, kiosk, and desktop civic engagement platforms

4.2 UI/UX Considerations for Deaf Users

Designing user interfaces for Deaf individuals requires centering their language and accessibility needs notably, prioritizing visual and interactive modalities over audio-centric cues. Chao (2025) used participatory design methods to reimagine video communication tools for Deaf users, revealing that traditional audiovisual UI paradigms systematically exclude sign-based communication participants. She demonstrates that Deaf users benefit from interfaces featuring persistent visual sign overlays, customizable video layouts, and integration of signer focus states. Similarly, according to Polanco Jr, & (2024), a Deaf full-stack developer emphasizes practical UX refinements: robust caption editing tools, explicit visual indicators (e.g., speaker flags, turn-taking cues), and deliberate avoidance of voice-activated interfaces that marginalize sign-preference users. From a design technicality standpoint, this means employing flexible UI frameworks that allow Deaf users to resize sign video panels, prioritize interpreter streams, and control playback speed (Imoh, et al., 2025). Visual hierarchy must de-emphasize background noise and audio cues, foregrounding signers and caption clarity. This not only fosters equitable engagement but also supports Deaf users' cognitive mapping during complex planning deliberations ultimately resulting in higher comprehension, reduced friction, and improved participatory satisfaction.

4.3 Integration of Sign Language and Multi-Modal Communication

Effective inclusion necessitates platforms that support rich multi-modal communication integrating sign language seamlessly with textual and visual content. Swanwick (2025) investigates Deaf children's communication in multilingual and multimodal contexts, demonstrating that simultaneous sign, gestural, and text prompts enrich comprehension compared to single-modality interfaces as represented in figure 3. This suggests urban platforms should adopt composite streams where sign, text, and visuals co-exist, enabling users to engage through their preferred modes. Bianchini et al. (2019) present a prototype inclusive framework where sign language, written cues, and interface gestures are cohesively combined—showing that users engage more efficiently when sign-based videos are synchronized with interactive textual buttons and iconographic navigation (Othman, et al., 2024). Technically, this requires synchronizing multiple media layers sign video, live captions, interactive overlays and ensuring they update in real time. Also essential is offering users modality toggles that respect language preference (e.g., sign-only, sign-plus-text, text-only) without losing context (Ijiga, et al., 2023). In urban planning forums, such multi-modal fusion ensures Deaf community members have equitable access to deliberation, information, and feedback loops, enriching democratic process fidelity.

Figure 3 illustrates how multi-modal communication can be systematically integrated into inclusive urban planning platforms to ensure accessibility for Deaf participants. At its core is the platform's communication hub, branching into three interconnected modalities. Branch 1 Sign Language Integration focuses on embedding real-time sign interpretation through human interpreters or AI avatars, supporting multiple sign languages, and ensuring interpreter video windows are persistently visible and resizable in the user interface. Branch 2 Text and Captioning Layer covers live speech-to-text captions, multi-language translation for textual content, and precise synchronization between captions and sign gestures to maintain semantic coherence. Branch 3 Visual and Interactive Cues enhances comprehension and engagement through clear iconography, clickable overlays linked to relevant sign language segments, and a multimodal feedback loop that allows users to select or switch communication modes on demand. Together, these branches create a layered, mutually reinforcing system where sign language, text, and visual cues work in harmony, enabling Deaf stakeholders to access, interpret, and contribute to complex policy discussions in real time.

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Figure 3: Diagram Illustration of Framework for Integrating Sign Language, Captions, and Visual Cues into Multi-Modal Urban Planning Platforms.

4.4 Case Studies of Accessible Urban Planning Platforms

Real-world implementations highlight how urban planning platforms can achieve Deaf inclusion. In a study of Nice, France, researchers established Deaf-friendly urban design criteria—drawing from DeafSpace principles such as visual signage, interpreter-equipped kiosks, and accessible public consultation booths; they demonstrated increased Deaf participation when planning events featured integrated sign communication and multimodal signage (Abdullah, 2024). Parallelly, Mačiulienė, & Skaržauskienė, (2020) maps international civic tech platforms, identifying platforms that include co-creation tools and multi-stakeholder interfaces as most effective; however, she notes a critical lack of explicit Deaf inclusion features—pointing to a design gap in participatory tech ecosystems. Together, these cases indicate that when urban platforms deliberately embed sign interpretation channels, visual wayfinding, and inclusive participation nodes, Deaf engagement rises significantly (Ijiga, et al., 2025). From a technical perspective, urban planning platforms should adopt modular designs accommodating interpreter windows, remote sign language sessions, and visual navigation aids. These case studies bolster our review's findings: that inclusive tech design must integrate Deaf communication norms from inception and through infrastructural deployment (Fagbohungbe, et al., 2025).

5. POLICY, ETHICS, AND IMPLEMENTATION STRATEGIES

5.1 Legal and Regulatory Frameworks Supporting Inclusion

Legal and regulatory frameworks offer essential scaffolding for embedding accessibility in civic technologies and urban governance. Shafik, (2025) emphasizes that robust policy environments must simultaneously address accessibility and security, recognizing that inclusive systems necessitate legal mandates to ensure digital civic platforms provide real-time interpretation and communication support. Complementing this, Biglieri (2025) examines urban planning policy gaps, noting that planners often lack statutory incentives to prioritize sensory or linguistic accessibility especially for Deaf citizens

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and that enabling legislation is essential to transform inclusive ideals into enforced norms. Together, these insights suggest that legal frameworks must go beyond general disability rights to require specific sign-language interpretation capacities within digital urban planning platforms. For instance, legislating mandatory real-time interpretation in civic engagement can close enforcement gaps that mere guidelines leave open. Such legal codification supports systemic inclusion and compels municipalities to allocate resources toward interpreter technologies, training, and monitoring (Ajiboye, et al., 2025). In absence of these mandates, even well-intended platforms may default to minimal compliance, perpetuating exclusion. Thus, realizing inclusive civic infrastructure requires both technical solutions and regulatory accountability embedded within planning law and digital governance standards (Imoh, 2023).

5.2 Ethical Design Considerations

Ethical design for inclusion demands reflexivity, equitable partnerships, and rigorous interrogation of power dynamics. Krawczyk (2024) highlights the necessity of ethically responsible engagement with Deaf communities, advocating for design practices that respect linguistic rights, cultural autonomy, and co-ownership in technology development as shown in table 4. Meanwhile, Desai et al. (2024) critique sign language AI research for systemic biases pointing out that projects often lack Deaf leadership, utilize non-representative datasets, and overlook interpretability or accountability of deployed systems (Desai et al., 2024). In designing civic platforms, these ethical exigencies imply more than adding sign-language features they demand inclusive governance processes where Deaf populations lead or co-design solutions, data sources reflect linguistic and cultural diversity, and interpretability is prioritized to foster trust (Fagbohungbe, et al., 2020). This entails transparent AI models that Deaf users can understand and audit, and design protocols that compensate and value Deaf experts' contributions (Ajiboye, et al., 2025). Ethical design thus intersects with epistemic justice: centering Deaf ways of knowing and communicating, while dismantling structural inequities inherent in many assistive technologies.

Table 4: Summary of Ethical Design Considerations

Ethical Concern	Description	Example or Insight	Implication for Inclusive Design
Power Imbalance in Design	Deaf contributors often lack decision-making roles in tech development	Projects frequently use Deaf participants as testers rather than co-creators	Empower Deaf leadership roles in design processes
Dataset Bias and Representation	Sign language models are trained on limited or unrepresentative data	Systems often exclude regional sign languages and diverse grammatical structures	Use diverse datasets and involve native signers during data collection
Cultural Sensitivity	Many platforms ignore Deaf culture and language norms	Tools built with hearing-centric assumptions undermine user trust and comprehension	Center cultural epistemologies in design protocols
Transparency and Accountability	Users must understand how systems work and make informed choices	Lack of explainability in AI models limits user agency	Build interpretable models and open-access documentation tailored for Deaf users

5.3 Collaboration Between Governments, Technologists, and the Deaf Community

Meaningful collaboration across sectors is pivotal for designing sustainable, inclusive civic technologies. (De Meulder et al., 2024) critically examine co-creation in EU sign-language technology projects, revealing persistent power imbalances and tokenistic inclusion of Deaf participants despite co-creation rhetoric as represented in figure 4. They argue that true partnership necessitates compensating Deaf collaborators, fostering Deaf leadership, and avoiding superficial engagement. Similarly, Suchanek (2025) explores co-design of makerspaces, demonstrating that projects structured around solidarity and mutual learning yield more equitable, usable outcomes for Deaf and hearing users alike. Transposed to urban planning platforms, these studies underscore that joint frameworks with formalized budgets for Deaf stakeholder roles, shared decision-making, and transparent governance constructs are critical (Ijiga, et al., 2023). Governments must recognize and fund Deaf-led design teams, technologists must adopt co-design methodologies respectful of Deaf cultural norms, and Deaf communities must be engaged not as consultants but co-equals in platform development. This collaborative triad ensures accessibility is not retrofitted but embedded as a shared priority.

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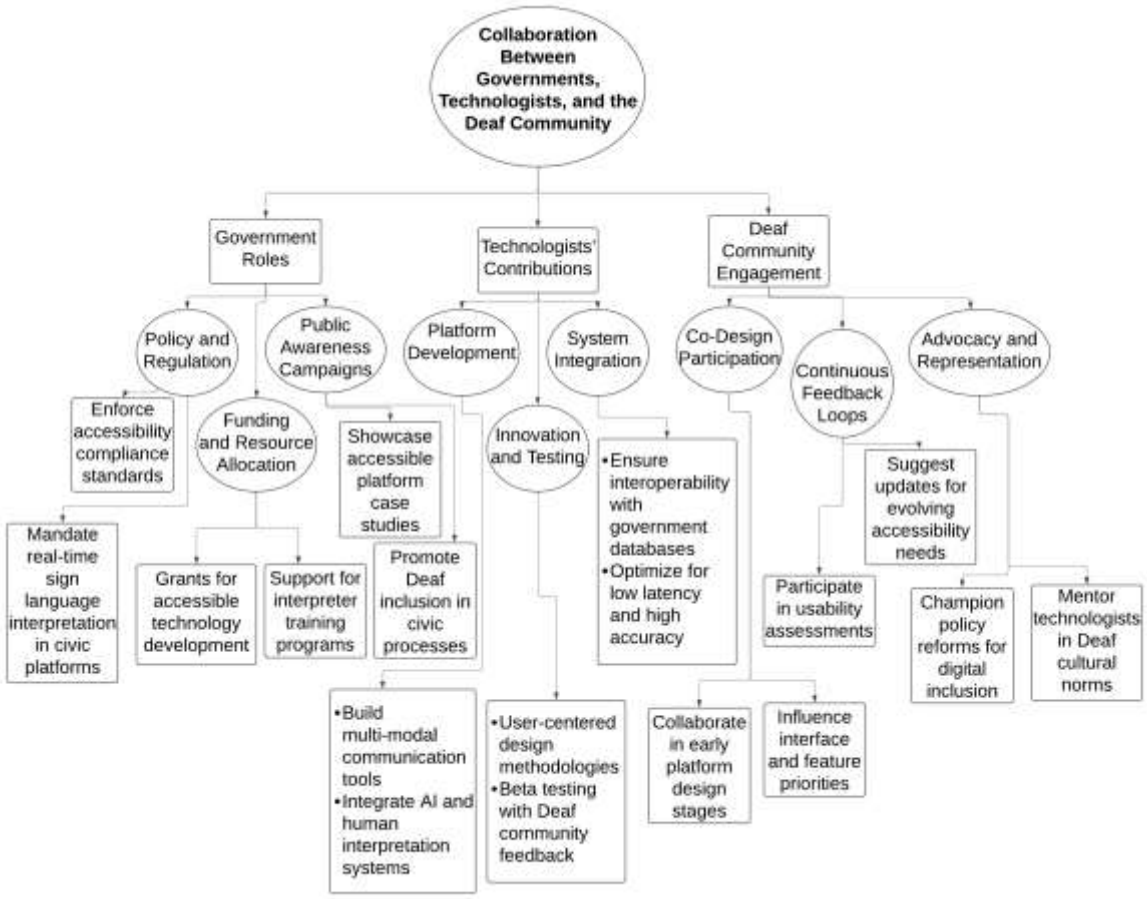

Figure 4: Diagram Illustration of Collaborative Model Linking Governments, Technologists, and the Deaf Community for Inclusive Urban Planning Platforms.

Figure 4 presents a structured collaboration model for developing inclusive urban planning platforms that effectively integrate real-time sign language interpretation and other accessibility features. At the center is the collaborative nexus linking governments, technologists, and the Deaf community, with each branch representing a key stakeholder group. Branch 1 – Government Roles outlines responsibilities such as establishing legal mandates for accessibility, allocating targeted funding for technology and interpreter training, and running public awareness campaigns that normalize Deaf inclusion in civic processes. Branch 2 – Technologists' Contributions focuses on building and refining the technical infrastructure, from developing multi-modal communication tools to integrating AI and human interpreters, while ensuring systems are low-latency, high-accuracy, and interoperable with government databases. Branch 3 – Deaf Community Engagement emphasizes active participation in co-design processes, continuous feedback loops to adapt to evolving accessibility needs, and advocacy to influence both policy reforms and cultural awareness among developers. Together, these branches form a closed-loop ecosystem where policy, innovation, and lived experience reinforce one another. This synergy ensures that accessible urban planning platforms are not only technically robust but also socially responsive, culturally sensitive, and aligned with the principles of participatory democracy.

5.4 Implementation Roadmap and Stakeholder Engagement

An effective implementation roadmap requires measurable performance indicators and alignment with broader rights-based policy strategies. Rebernik (2020) proposes a framework to assess urban inclusivity via sustainability indicators such metrics can be adapted to monitor civic platform accessibility, evaluating sign-language availability, user inclusion rates, and participatory equity. Complementarily, Šubic (2023) interprets national disability strategies as cultural policy instruments that operationalize rights-based inclusion across institutional domains. Drawing from these models, a roadmap for integrating real-time sign interpretation in urban platforms would begin with baseline assessments (e.g., current

accessibility scores), followed by phased deployment (pilot interpreters, platform enhancements), monitoring via inclusion metrics, and alignment with national disability strategies to ensure continuity and scale. Stakeholder engagement along the road must involve Deaf representatives, policymakers, technologists, and community advocates at each stage setting goals, evaluating usability, iterating features, and institutionalizing inclusive standards (Ijiga, et al., 2022). Such structured planning ensures that accessibility gains are measurable, accountable, and aligned with strategic governance frameworks.

6. CONCLUSION AND FUTURE DIRECTIONS

6.1 Summary of Key Insights

This review has illuminated the critical intersection between digital accessibility, urban planning, and Deaf community participation. It establishes that traditional civic engagement platforms often marginalize Deaf individuals by defaulting to audio-centric and text-heavy modalities without sign language integration. Real-time sign language interpretation emerges as a transformative feature that enables linguistic parity, allowing Deaf participants to access, understand, and contribute meaningfully to policymaking processes. The analysis also revealed that while technological advancements such as AI-driven sign recognition and avatar systems show promise, they must be embedded within inclusive platform designs that prioritize multimodal communication, low latency, and cultural responsiveness. Equally vital are the legal and ethical infrastructures that underpin platform design. Without enforceable accessibility mandates and ethical co-design practices, technological interventions risk reinforcing exclusion. The role of collaborative governance—where Deaf users, technologists, and urban policymakers co-create engagement platforms—was shown to be indispensable in bridging the systemic accessibility divide. Additionally, case studies demonstrated that inclusive planning interfaces do not only benefit Deaf communities; they foster broader participatory democracy, enhancing transparency, user trust, and civic satisfaction. Ultimately, this review positions real-time sign language interpretation not as a supplementary feature but as an ethical and democratic imperative in urban tech design—one that affirms the rights, agency, and voices of Deaf citizens in shaping equitable and responsive urban futures.

6.2 Implications for Urban Governance and Civic Technology

The findings of this study carry significant implications for the future of urban governance and civic technology. First, they challenge existing models of public participation that fail to accommodate the linguistic diversity and sensory needs of all citizens, particularly the Deaf community. Civic technology must evolve beyond digitization for convenience to digitization for inclusion. This requires a paradigm shift where Deaf-centered design principles—such as real-time sign interpretation, visual cue prioritization, and multimodal user engagement—are foundational, not optional. Urban governance systems must embrace inclusive policy frameworks that codify accessibility into procurement standards, platform audits, and digital service benchmarks. This transformation also necessitates adaptive technology infrastructure capable of integrating sign language avatars, AI-enhanced translation tools, and human interpreter options into city planning portals, feedback systems, and virtual town halls. In practical terms, government agencies should institutionalize accessibility through training modules, co-design partnerships, and accountability dashboards that report on inclusivity metrics. The implications extend to civic trust as well; inclusive platforms reinforce government legitimacy by ensuring marginalized voices are not just heard but structurally supported. In essence, embracing accessibility within civic technology reframes public engagement as a rights-based service rather than a privilege of the digitally literate majority, thereby strengthening the participatory foundation of democratic urban governance.

6.3 Recommendations for Future Research and Innovation

Future research must expand the technical, social, and policy dimensions of accessible civic engagement platforms to fully actualize the potential of real-time sign language integration. Technologically, there is a pressing need to refine AI-based sign language recognition systems for greater accuracy, expressive nuance, and multi-lingual sign support across diverse Deaf communities. Research should explore lightweight, edge-based solutions capable of delivering low-latency translation in bandwidth-constrained environments, particularly relevant for local governments in underserved regions. Moreover, the field should prioritize user-centered performance benchmarks—not just system accuracy, but comprehension rates, fatigue factors, and cultural comfort—validated through long-term user testing. Socially, future studies should delve into the lived experiences of Deaf users in digital civic spaces to inform platform enhancements grounded in real-world feedback. Ethnographic methodologies and participatory action research offer promising paths for deeper insights. From a policy standpoint, comparative research on international legal frameworks can identify best practices for mandating inclusive

digital participation. Additionally, innovation ecosystems should be fostered through public funding incentives for civic tech developers who co-create with Deaf communities. The creation of interdisciplinary research consortia that bring together sign linguists, urban planners, HCI experts, and policymakers would also accelerate ethical and scalable design. Collectively, such forward-looking research agendas will help transition civic platforms from reactive compliance to proactive inclusion.

6.4 Toward Equitable and Inclusive Smart Cities

Realizing truly equitable and inclusive smart cities requires a radical reconfiguration of how digital infrastructure, governance mechanisms, and civic identity are conceptualized. Deaf inclusion must not be viewed as a niche accessibility issue but as a benchmark for systemic inclusivity in urban innovation. To that end, smart city platforms must be reimagined as adaptive, multilingual, and multi-sensory ecosystems that reflect the full spectrum of human diversity. This entails embedding real-time sign language interpretation into all levels of public engagement—from virtual planning sessions and public comment dashboards to real-time policy deliberation platforms. These capabilities must be underpinned by cloud-based and edge computing architectures capable of processing gesture data, facial expressions, and linguistic markers without compromising speed or accuracy. Moreover, governance systems should institute digital equity audits and appoint accessibility officers to ensure continuous evaluation and refinement of inclusive practices. Infrastructural expansion must be paired with cultural transformation: planners and technologists must internalize Deaf epistemologies and commit to dismantling design hierarchies that prioritize hearing-centric interactions. By championing universal design, co-creation, and legislative accountability, smart cities can evolve into democratic spaces where difference is not merely tolerated but structurally supported. Ultimately, equitable smart cities will emerge not through technology alone, but through the intentional design of inclusive civic systems that elevate all voices—particularly those historically excluded from the dialogue of urban futures.

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