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NegevPulse

Crowdsourced Digital Mapping for Visibility in Unrecognized Bedouin Villages

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ABSTRACT

Urban Digital Twin (UDT) systems are increasingly central to data-driven urban governance, yet their effectiveness relies on comprehensive datasets. In informal settlements, where official data are missing, UDTs struggle to function. This paper introduces NegevPulse, a participatory digital mapping system designed for unrecognized Bedouin villages in the Negev, Israel. By integrating community knowledge through a trust-based crowdsourcing mechanism, the platform generates reliable spatial data to support navigation and emergency access. The study highlights how participatory mapping can address data poverty and extend the applicability of UDTs to undocumented spaces, promoting visibility and spatial justice.

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1. Introduction

In recent years, Urban Digital Twin (UDT) technologies have emerged as one of the most influential frameworks in urban planning, governance, and research. A UDT is typically defined as a dynamic, data-driven, and continuously updated digital replica of an urban system, capable of simulating infrastructure operations, monitoring urban performance, and supporting decision-making across scales (Grieves & Vickers, 2017; Nochta et al., 2021). Governments, municipalities, and private actors increasingly employ these models to optimize resource allocation, predict future scenarios, and enhance citizen services. Yet the promise of UDTs relies fundamentally on the availability of structured, reliable, and comprehensive datasets. Where data are missing, incomplete, or contested, the digital twin loses much of its applicability, raising critical questions about its inclusiveness and scope. This phenomenon—often termed *data poverty*—is particularly acute in informal or unrecognized settlements, where large populations are systematically excluded from official statistics, cadastral records, and digital infrastructures.

This article focuses on the Negev region of Israel, a site that vividly illustrates the consequences of data poverty. The Negev is home to tens of thousands of Bedouin residents who live in what are known as "unrecognized villages." These communities—lacking official state recognition—are excluded from statutory plans, cadastral registries, and most municipal records (Yiftachel et al., 2016). The absence of recognition produces a cascading set of challenges: villages are denied connection to electricity and water networks, their roads remain unpaved, and they have limited or no access to health services, waste collection, or public transportation. Beyond these infrastructural deficits, their exclusion is also digital. In official mapping platforms such as Israel's GovMap, unrecognized villages often appear only as scattered building footprints, stripped of street names, numbering systems, or road networks. In practical terms, this invisibility translates into severe difficulties for navigation, emergency services, and everyday mobility. Ambulances, fire trucks, and police units report critical delays in accessing unrecognized villages due to the lack of accurate geographic information. For residents, the absence of digital visibility exacerbates isolation, undermines safety, and reinforces inequality.

This challenge is not unique to the Negev. Across the Global South, informal settlements often remain digitally invisible: Kibera in Nairobi was long absent from official maps until community mapping initiatives intervened; favelas in Brazil frequently lack street names and numbering, complicating service provision; and refugee camps in Jordan and Lebanon still appear as blank areas in national cadastral systems (Bennett et al., 2020; UNITAR, 2023a; UNITAR, 2023b). These examples underscore that data poverty is a global phenomenon. Around the world, vast populations live in neighborhoods that are fully functional in practice yet erased in digital form. The emergence of participatory digital mapping has therefore been increasingly recognized as a necessary intervention to make invisible communities visible, bridging gaps between local knowledge and official infrastructures.

While these initiatives demonstrate the global relevance of participatory mapping, they often remain limited to the production of baseline geospatial data or one-off campaigns. In contrast, NegevPulse introduces a trust-weighted validation system that embeds community hierarchies of knowledge into the digital infrastructure itself. This socio-technical innovation not only ensures accuracy but also enhances legitimacy within the community, offering a replicable model for other contexts where data poverty intersects with contested recognition.

Against this background, the present study is guided by the following research question: How can participatory digital mapping address data poverty in informal settlements and extend the applicability of Urban Digital Twin systems to undocumented spaces?

To address this question, the article introduces NegevPulse, a participatory digital mapping platform developed to capture and formalize the geographic knowledge of unrecognized Bedouin villages. At its core, NegevPulse leverages crowdsourcing as both a technological and social mechanism. Residents actively contribute spatial information—routes, landmarks, and points of interest—via a mobile application, while a trust-based validation process ensures data quality by weighting contributions from "superlocals" (elders and long-term residents) more heavily than those of new users. In this way, the system aligns digital validation with existing social hierarchies of knowledge and authority. Unlike conventional crowdsourcing models that rely on majority votes or outsider contributions, this approach grounds digital representation in the community itself, ensuring both accuracy and legitimacy.

By embedding local knowledge directly into digital infrastructures, NegevPulse transforms vernacular navigation practices into structured geospatial datasets. Directions in Bedouin villages are often given through reference to landmarks, oral descriptions, and relational cues ("turn left after the school", "the mosque before the clinic") rather than formal addresses. NegevPulse captures these practices and converts them into standardized map data that can serve both residents and emergency responders. In doing so, the system demonstrates that crowdsourcing is not a peripheral add-on but the backbone of the digital twin's applicability in contexts of data poverty.

The contribution of this article is twofold. First, it addresses a theoretical gap by positioning informal settlements—and specifically unrecognized Bedouin villages in the Negev—within the discourse of Urban Digital Twins. While much of the literature on UDTs has focused on highly digitized urban environments, this study demonstrates that the concept can be extended to spaces of absence, where data poverty is the central condition. Second, it offers a practical innovation by presenting the design and development of NegevPulse as a model for integrating participatory, trust-based crowdsourcing into digital infrastructures.

The structure of the article reflects this dual contribution. Section 2 reviews the relevant literature on Urban Digital Twins, participatory GIS, crowdsourcing, and undocumented data. Section 3 introduces the Negev case study, focusing on the village of Wadi al-Na'am as a paradigmatic example of data poverty. Section 4 details the methodology and design of the NegevPulse system, including its trust-based validation mechanism. Section 5 presents the survey and mapping results that informed the application's development. Section 6, which combines discussion and conclusion, reflects on the broader implications of participatory mapping for extending the applicability of UDTs to informal settlements.

Ultimately, this study argues that addressing data poverty requires not only technological solutions but also socially attuned systems that value and integrate local knowledge. By centering crowdsourcing as a tool for producing reliable geospatial data, NegevPulse highlights how participatory digital mapping can transform communities that are currently invisible in official records into digitally represented, navigable, and recognized places. In doing so, it demonstrates that Urban Digital Twin systems can—and must—evolve to include undocumented spaces, expanding their role from instruments of optimization to mechanisms of equity and inclusion.

2. Literature Review

The integration of digital technologies into urban governance has generated new paradigms for representing and managing cities. Among these, the Urban Digital Twin (UDT) has become a central concept, defined as a data-driven and dynamic replica of urban systems designed to simulate, predict, and support decision-making (Grieves & Vickers, 2017; Nochta et al., 2021). While widely celebrated, most UDTs have been shaped by a techno-centric approach, emphasizing optimization and efficiency while neglecting questions of equity, representation, and justice. As scholars increasingly argue, digital infrastructures are never neutral; they embed particular assumptions about whose data is counted, whose voices are represented, and which spaces are made visible.

To address these shortcomings, Yossef Ravid and Aharon-Gutman (2023) proposed the notion of the Social Digital Twin (SDT), which repositions local knowledge, social indicators, and participatory practices at the core of digital twin architectures. The SDT framework challenges the assumption that official datasets are objective, instead foregrounding the social and political processes through which data are produced (Yossef Ravid & Aharon-Gutman, 2024). By explicitly incorporating social dynamics, this approach reframes UDTs not only as technical tools for optimization but also as socio-political infrastructures that must contend with issues of inclusion, representation, and power.

This perspective aligns with broader debates in the field of the smart city. Participation, while often touted as a principle of smart governance, has too frequently been reduced to tokenistic consultation or "checkbox" exercises (Cardullo, 2020). In contrast, participatory GIS (PGIS) offers an alternative model that allows communities to translate everyday spatial practices into formal datasets. PGIS approaches rely on co-production between experts and residents, generating knowledge that both enriches digital infrastructures and empowers marginalized communities (Haklay & Weber, 2008; Rambaldi, 2006).

Building on this, recent scholarship emphasizes the importance of place-bound planning support systems (PSS) that afford deliberation and enhance communication across diverse stakeholders (Weiner et al., 2023). Such approaches highlight that participatory mapping is not only about generating data but also about fostering mutual comprehension, dialogue, and legitimacy in contested urban spaces. By creating shared frames of reference, place-bound PSS strengthen the communicative capacity of planning tools, thereby improving both the accessibility and credibility of digital spatial knowledge.

The literature on crowdsourcing extends these arguments by demonstrating how distributed contributions can fill critical gaps in geospatial databases. Since Goodchild's (2007) influential notion of "citizens as sensors," platforms such as OpenStreetMap have shown the potential of large-scale volunteered geographic information (VGI). Yet, in marginalized contexts, conventional crowdsourcing methods—often based on simple majority voting—may fail to account for local power dynamics, cultural hierarchies, or sparse-data environments. This has led to proposals for alternative models such as trust-weighted validation, which align technological protocols with community authority structures. For example, privileging contributions from elders or long-term residents can significantly improve both accuracy and legitimacy (See et al., 2023; Senarath et al., 2020). Such models demonstrate that crowdsourcing is not merely a technical mechanism but a socio-technical process that reflects and reinforces local governance structures.

The importance of crowdsourcing is especially visible in informal and data-poor settings. For instance, the Map Kibera project in Nairobi demonstrated how participatory mapping could

transform an "invisible" settlement into a digitally represented community, thereby improving service provision and political recognition (Haklay, 2010). In Brazil, community mapping in favelas has revealed how the absence of official street names and numbering complicates postal delivery, census-taking, and emergency response, and how participatory mapping can help fill these gaps (Perkins & Dodge, 2008). Similarly, refugee camps in Jordan and Lebanon have often appeared as blank spaces in national cadastral systems, but initiatives led by UNOSAT and other humanitarian organizations have used satellite mapping and crowdsourced verification to generate usable datasets (UNITAR, 2023a; UNITAR, 2023b). These examples underscore that data poverty is not confined to a single context but represents a global phenomenon, disproportionately affecting the Global South.

The problem of undocumented or missing data further reveals the limits of mainstream digital infrastructures. In many unrecognized or informal settlements, key infrastructures, addresses, and entire communities are absent from official databases, producing what scholars call data poverty or digital erasure. Yiftachel's (2009) concept of "gray spaces" captures this condition: areas of permanent temporariness where residents are neither fully recognized nor entirely excluded, suspended between legality and illegality. This ambiguity allows states to withhold recognition and services while keeping communities under the constant threat of removal. In the Negev, unrecognized Bedouin villages exemplify such gray spaces, as their absence from maps and statistics translates into systemic exclusion from planning, difficulties in resource allocation, and life-threatening delays in emergency response.

Addressing these gaps requires both conceptual and technical innovation. Conceptually, it means expanding the discourse on UDTs to include informal and undocumented spaces, recognizing that data poverty is not a technical glitch but a structural condition rooted in governance and power relations. Technically, it means developing tools that can operate effectively in sparse-data environments, integrate vernacular practices of navigation, and validate contributions through socially attuned mechanisms. Crowdsourcing—particularly when designed to reflect local hierarchies of trust and authority—emerges here as a powerful strategy. Unlike conventional datasets that erase informal settlements, crowdsourced systems can build visibility from the bottom up, translating lived knowledge into digital infrastructures that matter for planning, emergency response, and everyday mobility.

Taken together, these debates highlight that digital urban technologies are never purely technical systems but socio-political infrastructures that shape visibility, power, and justice. The Social Digital Twin framework, informed by participatory GIS, place-bound planning support systems, culturally attuned crowdsourcing, and attention to undocumented data, provides the conceptual foundation for this study. It also frames the Negev case as an opportunity to reimagine how digital tools can redistribute visibility and access in marginalized contexts, thereby extending the scope of Urban Digital Twins from instruments of optimization to mechanisms of inclusion and spatial justice.

3. Case Study: Unrecognized Bedouin Villages and the Case of Wadi Al-Na'am

In the Negev/Naqab region, approximately 100,000 Bedouin residents live in unrecognized villages, representing one of the most prominent examples of communities excluded from Israel's official planning frameworks (Yiftachel et al., 2016). These villages are not included in statutory plans and therefore do not appear in governmental cadastral systems or municipal records. As a result, they

remain outside most formal infrastructures and are excluded from the systematic provision of basic services.

The absence of recognition is reflected in everyday life. Most unrecognized villages are not connected to the electricity grid, water network, or sewage systems. Roads are often unpaved and become difficult to navigate during winter, which hampers school attendance and delays emergency medical access. Public services such as waste collection, health facilities, and transportation are either minimal or entirely absent, forcing residents to rely on alternative solutions such as generators, solar panels, and private vehicles.

The unrecognized status also produces gaps in digital representation. In governmental mapping systems such as GovMap, many villages appear only partially, if at all. Even when building footprints are marked, they are often represented as isolated structures without addresses, numbering, or road networks. This partial digital visibility does not reflect the coherent social and spatial fabric of these communities, which exist in practice but remain underrepresented in official data. The lack of reliable geospatial information has practical implications, particularly for emergency services and resource allocation, which depend on accurate maps.

The case of Wadi Al-Na'am, an unrecognized village located east of Be'er Sheva, illustrates these dynamics in a concrete way. Home to several thousand residents, Wadi Al-Na'am has developed informal networks of housing clusters, circulation routes, and community-based infrastructures. However, its absence from formal planning frameworks leaves it without secure tenure, without integration into municipal systems, and with limited access to essential services. Wadi Al-Na'am exemplifies what Yiftachel (2009) terms a gray space: a locality suspended between legality and illegality, tolerated in practice yet always vulnerable to removal.

A clear example of this gap is shown in Figure 1, which juxtaposes the GovMap vector layer (left) with an aerial orthophoto (right). In the vector map, Wadi Al-Na'am appears as scattered building footprints without any road system or addresses. By contrast, the aerial image demonstrates the lived reality of the village: a coherent built environment with housing clusters, connecting paths, and everyday spaces.

This comparison highlights the challenges posed by undocumented data. While official systems recognize individual structures, they fail to capture the settlement as a functioning community. The absence of comprehensive digital representation not only obscures the spatial logic of the village but also complicates emergency response, planning, and the delivery of services. As Haas and Tzfadia (2025) argue, this condition constitutes displacement-in-place: residents remain on their land but experience the erosion of rights, recognition, and security. In this sense, Wadi Al-Na'am is not an exception but a critical example of how digital erasure and contested recognition intersect to shape Bedouin precarity in the Negev.

Figure 1. GovMap vector layer of Wadi Al-Na'am (left) and aerial orthophoto (right). Sources: GovMap, Israel Government Mapping Portal.

Source: Own elaboration, 2025.

4. Methodology

The methodological design of this study reflects its dual ambition: to ground the project in empirical evidence of local spatial knowledge and to translate these insights into a technological platform for participatory mapping. Drawing on the literature on Participatory GIS (Haklay & WEBER, 2008; Rambaldi, 2006) and trust-based crowdsourcing (Senarath et al., 2020), the research was structured in two complementary phases.

4.1. Survey -Data collection, perceptions analysis

In the first phase, we designed and administered a GIS-enabled survey targeting residents and visitors of Wadi Al-Naam to collect spatial information on navigation difficulties, map familiarity, infrastructure challenges, and landmark recognition. Using ArcGIS Survey123 Connect, the instrument incorporated interactive, map-based items that allowed respondents to mark points, routes, and areas directly on the map. These inputs yielded participant-generated geospatial data that enabled a more precise characterization of local navigational and infrastructural conditions. The aim of this phase was to elicit actionable community knowledge to inform enhancements to public mapping services and guide future infrastructure planning. In total, 33 individuals (15 males; 18 females) participated in the survey, 13 residents and 20 non-residents providing a diverse and insightful datasetThe survey is available in ESRI link for residents and for non residents

While the sample size (n=33) is modest, it was intentionally designed as a pilot study to test the feasibility of participatory mapping in unrecognized villages. The focus was not on statistical representativeness but on capturing diverse perspectives—residents with deep local knowledge alongside non-residents with external viewpoints. This design provided sufficient variety to identify key navigational challenges, validate the trust-weighted algorithm, and generate insights to guide further development of the NegevPulse platform. Future research will expand the sample to evaluate scalability and broader applicability.

4.2. Phase 2 Application Development and Crowdsourced Mapping

The second phase built on these findings and shifted the focus toward technological development. Here, the emphasis was on designing and implementing the NegevPulse platform, a participatory digital mapping tool underpinned by a trust-weighted crowdsourcing algorithm. This phase demonstrates how localized, community-driven knowledge can be systematically integrated into a digital infrastructure that serves both residents and external actors such as emergency services.

4.2.1. Trust-Based Voting Algorithm with Tiered Visibility

One of the core innovations in the NegevPulse platform is the development and deployment of a trust-weighted community validation algorithm. This mechanism was designed to ensure the reliability of crowdsourced spatial data in contexts where no official mapping authority exists, such as in unrecognized villages. Unlike conventional platforms that treat all user inputs equally, NegevPulse distinguishes contributors by assigning differential trust weights based on their community status and mapping accuracy.

The platform defines three types of contributors:

- Regular Residents (weight = 1): All users with basic registration and minimal mapping history.
- Active Residents (weight = 2): Users who have either contributed ≥2 verified landmarks or achieved ≥80% voting accuracy across at least five voting sessions.
- Superlocal Residents (weight = 4): Long-term residents (≥5 years) nominated by the community, who have voted correctly (i.e., in alignment with final verification) at least 10 times and contributed ≥2 verified features.

When a user submits a new landmark or route, it enters a pending status and is only visible to registered community members. It does not appear to external users or visitors until validated. To achieve verified status, a submission must meet two thresholds:

1. It must receive votes from at least five unique users.
2. The weighted sum of "accept" votes must reach or exceed a defined threshold: T = 5.6.

This is calculated using the following formula:

Figure 2. Trust-based validation formula for feature verification in NegevPulse. The equation defines the threshold condition for a submitted landmark or route to be accepted based on the cumulative weight of approving votes.

$$\sum_{j=1}^{|v|}(w_j \times v_j) \geq T$$

A weight w_i :

$$w_i = \begin{cases} 1 & Regular\ Resident \\ 2 & Active\ Resident \\ 4 & Superlocal\ Resident \end{cases}$$

- A binary vote $v_i \in \{1,2\}$ (reject/accept)
- Counters:
  - c_i: *Total votes* cast.
  - s_i: Votes matching final verification.

Source: Own elaboration, 2025.

These metrics enable dynamic trust assignment and user promotion across tiers. A Regular Resident who repeatedly votes in alignment with community consensus, for example, can be elevated to Active or even Superlocal status.

This trust-based framework strikes a balance between openness and data quality, empowering inclusive participation while safeguarding the platform from misinformation or accidental errors. Importantly, it reflects social hierarchies and experiential authority within the community itself, offering a socio-technical model of mapping that is both robust and culturally embedded.

Equation 1. crowd source mechanism based on trust-based voting algorithm

A weight w_i:

$$w_i = \begin{cases} 1 & \text{Regular Resident,} \\ 2 & \text{Active Resident,} \\ 4 & \text{Superlocal Resident.} \end{cases}$$

A binary vote $v_j \in \{0, 1\}$ (reject/accept).

Counters:

- c_i: Total votes cast.
- s_i: Votes matching final verification.

Verification Condition:

User Promotion Rules:

1. **Regular → Active Resident:**

$$\text{If } u_i \text{ submits } \geq 2 \text{ verified landmarks/routes} \implies w_i \leftarrow 2.$$

2. **Active → Superlocal Resident:**

$$\text{If } c_i \geq 10 \wedge s_i > 10 \implies w_i \leftarrow 4.$$

A landmark/route is verified if the weighted sum of "accept" votes meets threshold $T = 5.6$:

$$\sum_{j=1}^{|V|} w_j \cdot v_j \geq T$$

Source: Own elaboration, 2025.

The trust-based model is not purely technical—it encodes the social hierarchies of knowledge within the community. By elevating the authority of *Superlocals* while keeping the system open to all

residents, the application reflects the lived expertise of those most embedded in the village. At the same time, it guards against misinformation or malicious entries, which are common concerns in open crowdsourced platforms.

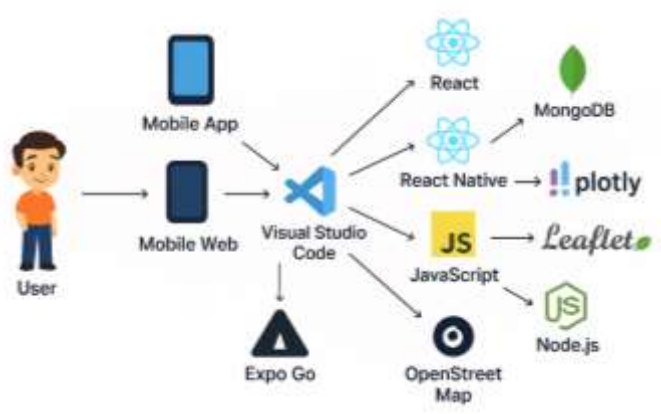
Furthermore, the model integrates cultural sensitivity: certain locations marked as socially or culturally sensitive (e.g., cemeteries, private gathering spaces) remain visible only to residents, never to external users. This selective visibility acknowledges that digital representation is also a political act, requiring protection of community autonomy over what becomes visible and what remains restricted.

4.2.2. Development environment

The application was designed as a cross-platform system accessible through both mobile web and native mobile app interfaces. Development relied on React and React Native for the user interface, JavaScript for client-side logic, and MongoDB and Node.js for backend data management. Geospatial visualization was enabled by Leaflet and OpenStreetMap, while Expo Go facilitated rapid prototyping and testing.

The architecture (Figure 3) ensures modularity, scalability, and open-source compatibility, allowing the platform to be adapted to other informal settlements. Importantly, the use of open geospatial standards enables interoperability with existing municipal and humanitarian GIS infrastructures, thus bridging the gap between grassroots mapping and formal datasets.

Figure 3. Technical architecture of the NegevPulse application, integrating front-end, back-end, and geospatial data processing.



Source: Own elaboration, 2025.

5. Results

The Results chapter is organized into two parts: the survey findings and a description of the application.

5.1. Survey results

5.1.1. Residents' Knowledge and Attachment

As the primary knowledge holders of Wadi al-Na'am, residents demonstrated exceptionally strong familiarity with the village landscape. On average, respondents reported living in Wadi al-Na'am for nearly three decades, with over 90% indicating they had lived there since birth. This long-term residency translates into a rich reservoir of knowledge about landmarks, circulation routes, and spatial orientation practices.

Residents consistently referred to key community anchors when guiding others through the village. The most frequently cited landmark was the *Electric Company*, mentioned by over 75% of respondents. Additional reference points included local shops, mosques, the school entrance, and the night clinic. Directions were often supplemented by relational or social cues, such as *"I will wait for you"* or *"before you reach the mosque, turn left"*, underscoring that navigation is not only spatial but also embedded in practices of hospitality and social interaction.

Figure 4. Word cloud of terms used by residents when giving verbal directions in Wadi al-Na'am

Source: Own elaboration, 2025.

Residents also expressed a high willingness to share local knowledge. Over 60% selected the highest level of engagement when asked whether they would contribute to participatory mapping platforms, and an additional 23% reported strong willingness. This enthusiasm signals both the urgency of addressing infrastructural deficits and the community's readiness to actively participate in digital solutions.

5.1.2. Non-Residents' Perspectives and Navigation Challenges

By contrast, non-resident participants provided an external perspective shaped by less frequent and more fragmented interaction with the village. While 60% had visited Wadi al-Na'am at least once, only 15% reported regular visits. For these participants, navigation challenges were acute: nearly all reported difficulties using GPS-based services, with 80% noting that Waze—the only platform they used—was often inaccurate or failed entirely. No respondents reported using Google Maps or

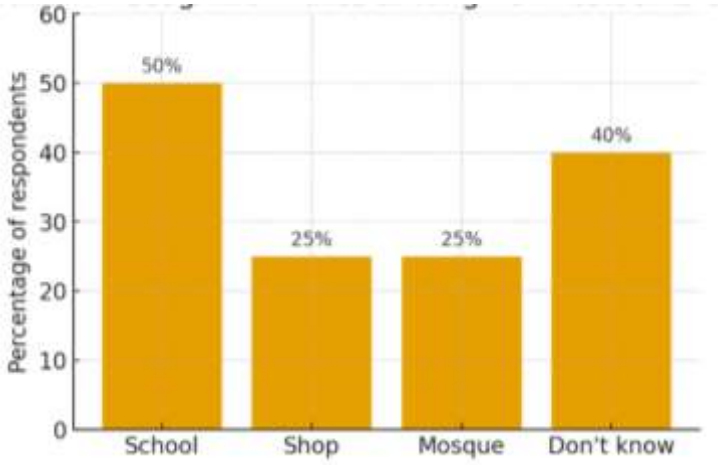
OpenStreetMap, highlighting both the dominance and the limitations of commercial navigation tools in informal settlements.

When asked to identify landmarks, non-residents most frequently recognized the Alazazmah School (50%), followed by the Algergawi Mosque and Algergawi Shop (each 25%). Compared to residents' emphasis on the Electric Company and other everyday community anchors, non-residents tended to rely on more formal, regionally recognizable institutions

Figure 5. Spatial points within Wadi al-Na'am that lack representation in official digital mapping platforms (e.g., GovMap, Google Maps, Waze). Despite their absence from state or commercial datasets, local residents consistently assigned names to these sites, linking physical locations to vernacular place-names. This illustrates how community knowledge provides a parallel layer of spatial information, compensating for the

digital invisibility of unrecognized villages.
Source: Own elaboration, 2025.

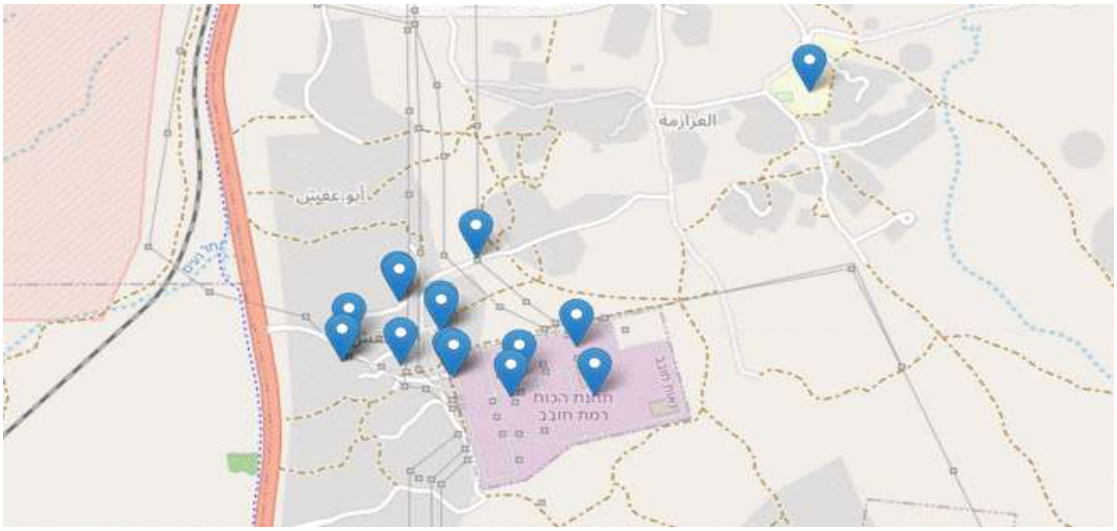
Figure 6. Landmark recognition rates among non-residents of Wadi al-Na'am. While half of the participants recognized the school as a central landmark, fewer identified other sites such as the shop or mosque. A substantial proportion of respondents expressed uncertainty, highlighting the absence of standardized names and digital visibility in official mapping systems.



Source: Own elaboration, 2025.

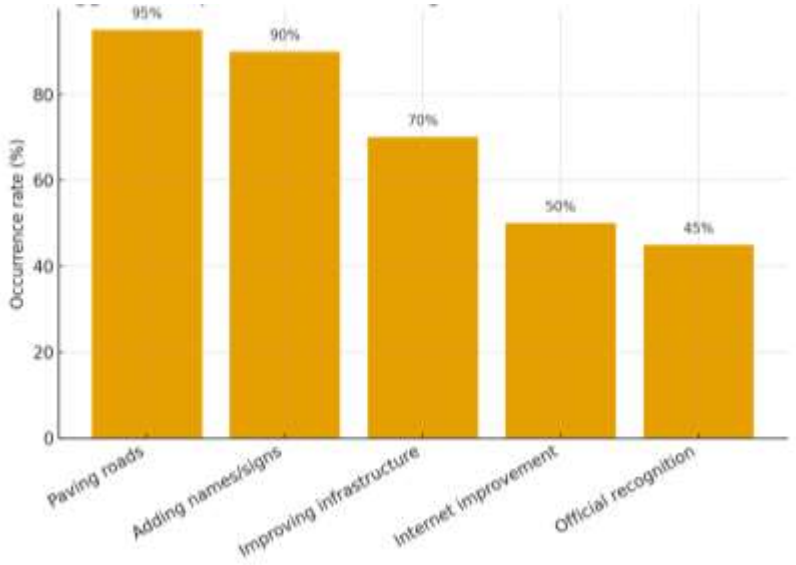
Non-residents also highlighted the physical and digital barriers that shape access to Wadi al-Na'am. Unpaved roads, the absence of street names, and poor internet connectivity were cited as the most significant obstacles. Suggestions for improvement emphasized paving roads and introducing street signage, with some participants explicitly linking these needs to the broader question of official recognition.

Figure 7. Locations of landmarks identified by residents in the survey.
Residents marked a dense network of local landmarks, paths, and junctions, attaching names to undocumented spaces. This illustrates the richness of local spatial knowledge compared to non-residents



Source: Own elaboration, 2025.

Figure 8. Suggested improvements for navigation and infrastructure in Wadi al-Na'am. Survey participants emphasized paving roads and adding names/signs as the most urgent needs, followed by general infrastructure upgrades, improved internet access, and official recognition of the village.



Source: Own elaboration, 2025.

5.1.3. Shared Patterns and Implications

Despite differences in perspective, both residents and non-residents demonstrated a reliance on landmark-based navigation. Half of non-residents reported using landmarks to find their way, mirroring the practices of residents, though with different reference points. This convergence underscores the critical role of landmarks in contexts where formal addressing and signage are absent.

Taken together, the survey results confirm two central insights. First, residents of Wadi al-Na'am possess detailed, reliable, and socially embedded spatial knowledge that can be harnessed to fill the gaps of formal datasets. Second, existing digital mapping services are inadequate in such contexts, failing both locals and visitors. These findings provide the empirical basis for the development of NegevPulse, the participatory mapping application described in the next chapter, which translates community knowledge into structured, validated digital data.

5.2. Application Description

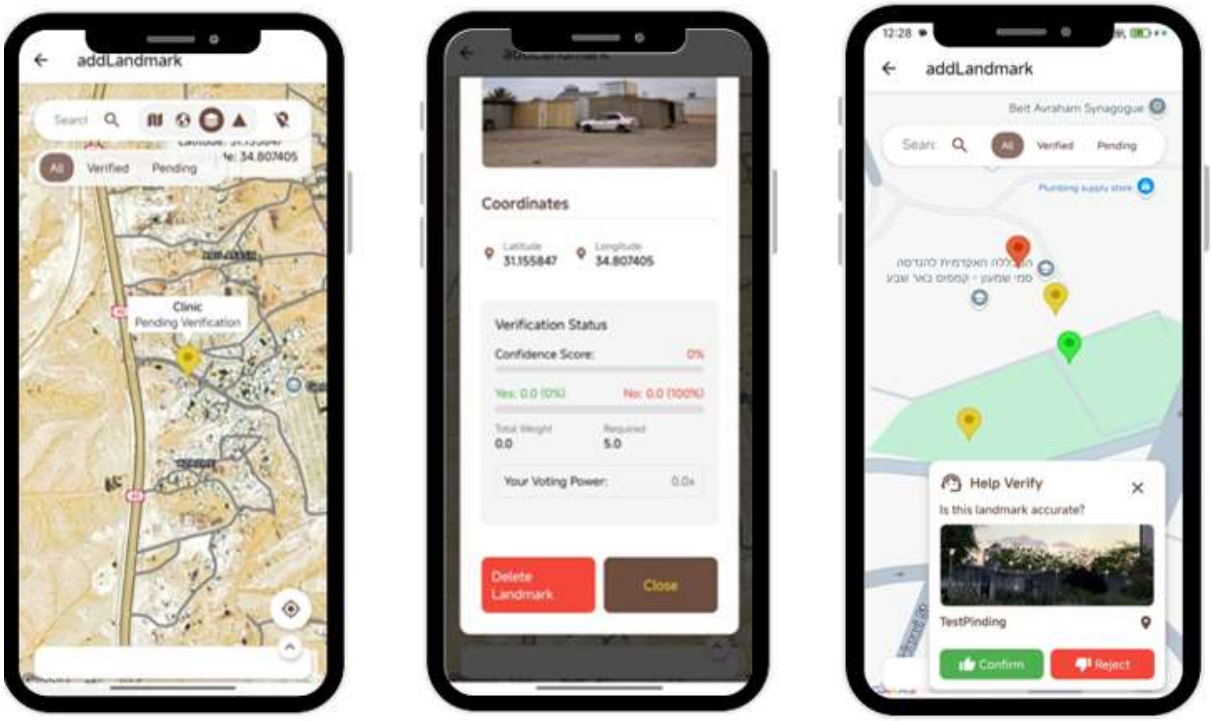
Building on the survey findings, which highlighted both the depth of residents' local spatial knowledge and the navigation challenges faced by outsiders, we developed NegevPulse, a participatory digital mapping application tailored to the context of unrecognized villages. The platform is not merely a technological tool but a socio-technical system that operationalizes community knowledge into structured, validated digital layers.

The NegevPulse interface was designed to be intuitive and accessible even to users with limited digital literacy. Users can:

- Add landmarks or routes by tapping directly on the map or uploading geotagged photographs.
- Update existing features with descriptive text, multimedia, or corrected coordinates.
- Validate contributions by voting on pending entries, using simple approve/reject buttons.

New submissions appear as *pending* (grey icons), and only after community validation do they transition into *verified* features (blue icons). Emergency-related features (e.g., water points, clinics) receive priority visibility to designated emergency responders.

Figure 9. User interface of the NegevPulse mobile app: adding a landmark (left), validation screen (center), and confirmation interface (right).



Source: Own elaboration, 2025.

6. Discussion and Conclusion

The increasing adoption of Urban Digital Twin (UDT) technologies across urban governance underscores the growing reliance on data-driven planning and decision-making. Yet this reliance presupposes the existence of reliable, structured, and comprehensive datasets—an assumption that fails in contexts marked by data poverty. Informal settlements, such as unrecognized Bedouin villages in the Negev, exemplify this challenge. These communities are not only excluded from official planning and infrastructural systems, but also from digital visibility. Their absence from national GIS platforms, navigation services, and formal cadastral records translates into both practical disadvantages (e.g., delays in emergency response) and symbolic marginalization (e.g., invisibility in the urban imaginary).

The findings of this study show that data absence does not equate to knowledge absence. Residents of Wadi al-Na'am demonstrate a rich, consistent, and socially embedded spatial knowledge—one that enables them to navigate, identify, and describe their environment using local landmarks and shared reference points. This knowledge, while vernacular and oral in form, is highly structured and reliable. The initial GIS-based survey confirmed the community's capacity and willingness to contribute this knowledge to participatory platforms, particularly in response to critical needs like emergency access, navigation, and basic infrastructure.

Building on these insights, the NegevPulse platform was developed as a socio-technical tool to formalize and validate local knowledge through a trust-based crowdsourcing mechanism. Unlike conventional digital mapping tools that treat all contributions equally, NegevPulse introduces a tiered user model that weights contributions from long-term, trusted residents—"Superlocals"—more heavily. This approach aligns digital validation with existing social hierarchies and cultural practices, while safeguarding against misinformation and misuse. The platform's technical architecture further allows for selective visibility of sensitive landmarks, prioritization of emergency-related data, and continuous data refinement based on community consensus.

Beyond its local applicability, the broader contribution of this study lies in reframing the role of participatory digital mapping in informal contexts. In settings of infrastructural marginalization and digital invisibility, crowdsourcing is not merely a data collection method—it becomes a mechanism for asserting presence, claiming space, and resisting displacement. While official systems may exclude or erase these communities, participatory platforms such as NegevPulse offer a bottom-up alternative that restores both visibility and agency.

This reframing is critical for extending the applicability of UDTs beyond the well-mapped and digitized city cores. If digital twins are to serve as equitable planning tools, they must evolve to include undocumented environments and marginalized communities. NegevPulse represents a replicable model for such an evolution. It demonstrates that spatial data can be co-produced with communities, and that digital infrastructures can reflect local knowledge, cultural sensitivity, and dynamic social validation.

In conclusion, the case of Wadi al-Na'am illustrates that participatory digital tools can do more than fill technical gaps—they can challenge spatial displacement and reinforce community presence in the face of systemic exclusion. Future work should explore the scalability of this model, its integration with municipal systems, and its governance implications. As cities become more data-reliant, ensuring that all communities—documented or not—can participate in the digital layer of urban life is not just a technical necessity, but a matter of spatial justice.

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