

Digital Waste and Communicative Noise in Age-Friendly Municipal Communication

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Abstract

This article conceptualizes municipal digital communication as an urban infrastructure that generates cognitive externalities, thereby contributing to debates on the (un)sustainability of digitalization. While the literature has paid more attention to the material- and energy-related impacts of digital infrastructures, it has somewhat overlooked how these systems shape access to, understanding of, and use of public information. To fill this gap, this study develops an integrated analytical model based on four dimensions: digital waste, communicative noise, cognitive accessibility, and institutional orientation toward older adults. Empirically, the analysis is based on a systematic content analysis of the digital communication infrastructures of 20 municipalities belonging to the Spanish Network of Age-Friendly Cities and Communities. Composite indices capture structural dysfunctions and communicative capacities through descriptive and configurational analyses. Communicative noise (mean = 0.41) is more prevalent than digital waste (mean = 0.33), indicating that fragmentation and navigation incoherence are the main sources of inefficiency. A further gap between cognitive accessibility (mean = 0.34) and institutional orientation toward older adults (mean = 0.28) undercuts the inclusiveness of digital environments. The configurational analysis identifies critical systems as the largest group (35%), followed by advanced and hybrid systems (20% each), while three cases remain indeterminate because of missing dysfunction data. The article introduces communicative sustainability as an emergent condition for realizing public value through urban digital infrastructures.

Keywords

age-friendly cities; cognitive accessibility; communicative sustainability; digital waste; municipal communication; urban digital infrastructures

1. Introduction

Digitalization has become well established as a structural dimension of contemporary urban planning. At the local level, municipal digital environments facilitate access to information, services, and participatory processes; therefore, they can no longer be understood solely as management tools or dissemination channels, but rather as part of urban infrastructure itself. However, the development of these infrastructures raises an issue that has not yet been adequately addressed: In addition to their functional benefits, digital systems can generate cognitive costs due to the accumulation of information, the fragmentation of navigation paths, and the lack of consistency in the presentation and organization of their content.

This issue has received uneven attention in the literature. Discussions of digital sustainability have concentrated mainly on the material- and energy-related externalities of digitalization (Belkhir & Elmeli, 2018; Frenken & Schor, 2017; Martinez, 2023), whereas research on digital governance and e-government has more often examined service delivery, administrative innovation, and multichannel institutional arrangements (Gil-Garcia et al., 2016; Janssen & Estevez, 2013; Mergel, 2013). Although both perspectives have made significant contributions, the informational conditions of municipal digital ecosystems remain less developed: These systems can shift the burden of locating, interpreting, and using public information onto citizens.

This issue is particularly relevant in the context of age-friendly cities and communities. Communication and information are among the core aspects of urban age-friendliness, but their progressive digitalization is reshaping the actual conditions for accessing resources, rights, and opportunities for participation. In this context, the mere availability of content or channels is not enough to ensure communicative inclusion. It also matters how the information is structured, how understandable the interfaces are, and to what extent public institutions explicitly recognize older adults as the target audience of their communication efforts.

Based on this approach, this article conceptualizes municipal digital communication as an urban infrastructure that generates cognitive externalities. To this end, it proposes an integrated analytical model based on four dimensions: digital waste, communicative noise, cognitive accessibility, and institutional orientation toward older adults. While the first two dimensions make it possible to identify forms of structural inefficiency related to redundancy, obsolescence, and the fragmentation of the communication system, the second two allow for an examination of the system's functional and procedural capacities to facilitate a more understandable and inclusive relationship between citizens and institutions.

Based on this framework, the study pursues two complementary objectives. First, to identify patterns of inefficiency and capacity in the digital infrastructures of municipalities forming part of the Spanish Network of Age-Friendly Cities and Communities. Second, to analyze how these dimensions combine to form distinct configurations of municipal communication systems. Empirically, the study is based on a systematic content analysis of 20 municipalities, supplemented by the development of composite indices and a configurational analysis aimed at identifying typologies.

This article makes three contributions. At the theoretical level, it expands the debate on digital sustainability by incorporating the informational and cognitive dimensions of urban systems. At the analytical level, it proposes an integrated framework for studying municipal communication that transcends the mere

availability of resources or channels. At the applied level, it provides an empirical foundation for assessing local communication infrastructures from an inclusion perspective, which is relevant for age-friendly urban planning and for the subsequent development of participatory evaluation and intervention strategies.

2. Theoretical Framework

2.1. *Digital Sustainability and Cognitive Externalities*

Digitalization has become a central component of contemporary urban planning, linked to goals of efficiency, innovation, and sustainability. However, from a systemic perspective, this process is not neutral. Along with its benefits, it generates other externalities that are not limited to the material or energy costs of technological infrastructure, but also affect the way in which the public accesses, understands, and uses public information.

The literature on digital sustainability has made progress in identifying the environmental impacts of technological infrastructure, particularly in terms of energy consumption, carbon footprints, and the expansion of data storage and processing systems (Belkhir & Elmeligi, 2018; Frenken & Schor, 2017; Martinez, 2023). However, less attention has been paid to the informational dimension of these systems. At the same time, research on information overload has shown that an increase in the amount of information available can have negative effects on processing capacity, decision-making, and the user experience (Bawden & Robinson, 2009; Eppler & Mengis, 2004).

From this perspective, it is necessary to broaden the concept of digital sustainability to include the cognitive conditions of using information systems. In digitized urban environments, the accumulation of content, information redundancy, and the structural complexity of platforms can give rise to cognitive costs that directly impact the effective accessibility of information. These cognitive externalities represent a dimension that has been largely overlooked in the literature, but which is relevant for understanding how digital infrastructures function in urban governance contexts.

2.2. *Municipal Communication as an Integrated Digital Governance Infrastructure*

At the local level, municipal digital communication can be understood as an integrated infrastructure that organizes access to services, rights, and participatory processes. From this perspective, it is not merely a set of dissemination channels, but rather a system that structures the interaction between citizens and institutions, shaping the effective conditions for access to public information (Campillo-Alhama & Martínez-Sala, 2017).

This approach accords with digital-governance research on the increasing complexity and systemic nature of public information ecosystems (Gil-Garcia et al., 2016; Janssen & Estevez, 2013). From a public-value perspective, however, the availability of technology or online services cannot itself be treated as an outcome. ICT-enabled reform creates public value only insofar as technological and organizational arrangements help produce collectively valued consequences, including effective access, responsiveness, participation, inclusion, and trust (Cordella & Bonina, 2012). This distinction shifts attention from digital provision to the institutional conditions under which digital capacities become usable and socially meaningful.

Platform-governance research further shows that this conversion is not automatic. Government platforms require institutional orchestration across services, actors, information flows, and interfaces; weak coordination can fragment access and restrict the value that platforms are capable of producing (Cordella & Paletti, 2019). Municipal evidence also suggests that platforms can support value co-creation when they broker bidirectional flows among citizens, administrations, and service providers rather than operating as isolated dissemination channels (Mersico et al., 2026). In this article, structural coherence, cognitive accessibility, and explicit orientation toward older adults are therefore treated as enabling or eroding conditions for the potential realization of public value. The study observes these infrastructural conditions; it does not directly measure public value as experienced by citizens.

2.3. Aging, Cognitive Accessibility, and the Digital Divide

These issues become even more relevant in the context of age-friendly cities and communities, where communication and information are one of the structural domains of urban friendliness (World Health Organization [WHO], 2007). Digitalization is reshaping this domain by shifting institutional interaction to web environments, online portals, and digital platforms, which has the potential to expand access, but also creates new barriers.

Research has shown that interaction with digital systems is influenced by factors such as cognitive load, prior experience, and interface design, with particularly significant effects on older adults (Czaja et al., 2006; Friemel, 2016; Sayago & Blat, 2011). In this regard, cognitive accessibility, defined as the ability of systems to facilitate understanding through clear language, hierarchical structures, and predictable navigability, is a key element of digital inclusion.

Cognitive accessibility alone, however, does not exhaust the dimension of inclusion. In addition to cognitive accessibility, it is necessary to consider institutional orientation toward older adults as a stakeholder group. While accessibility refers to the functional properties of the system, the targeting of content involves explicit decisions about who the communication is aimed at, how it is made visible, and where it is positioned within the information architecture. Recent literature has shown that digital systems tend to reproduce inequalities when they are designed based on assumptions of a homogeneous user population, without explicitly taking into account the needs of specific groups (Kolotouchkina et al., 2023; Neves et al., 2018; Seifert, 2020).

2.4. Analytical Dimensions of the Digital Communication Sustainability Model

Based on this, the analysis of municipal digital communication can be structured around four interrelated analytical dimensions: digital waste, communicative noise, cognitive accessibility, and institutional orientation toward older adults. Table 1 summarizes the main contributions from the literature regarding these dimensions and enables the proposed model to be placed within the context of existing debates.

The first two dimensions capture forms of structural inefficiency in the communication system. Digital waste refers to the accumulation of redundant, obsolete, or low-functional-value content, which increases the cognitive load required for people to locate relevant information. Communicative noise refers to the fragmentation of information across channels and its structural inconsistency, which makes it difficult to reconstruct coherent navigation paths.

Table 1. Conceptual summary of the literature and analytical dimensions of the digital communication sustainability model.

Analytical dimension	Operational concept	Representative literature	Main contribution	Limitation identified
Digital waste	Information redundancy and obsolescence	Bawden and Robinson (2009); Belkhir and Elmeligi (2018); Eppler and Mengis (2004); Frenken and Schor (2017)	Identifying the externalities of digitalization and the increasing information overload	Limited attention to how information redundancy and obsolescence affect the user experience
Communicative noise	Multichannel fragmentation and lack of coordination	Bannister and Connolly (2011); Gil-Garcia et al. (2016); Janssen and Estevez (2013); Mergel (2013)	Analysis of the complexity of digital ecosystems and institutional coordination	Insufficient integration of the cognitive dimension of access
Cognitive accessibility	Comprehensibility and navigability	Czaja et al. (2006); Sayago and Blat (2011); Norman (2013); U.S. General Services Administration (2023); World Wide Web Consortium (2025)	Evidence on factors related to comprehension, orientation, and the use of interfaces	Predominantly design- and usability-centered approaches, with limited integration of institutional and public-governance perspectives
Institutional orientation toward older adults	Age-friendly inclusion	Kolotouchkina et al. (2023); Reuter et al. (2020); Seifert (2020); WHO (2007)	Identifying digital inequalities and recognizing the specific needs of older adults	Limited operationalization in specific digital systems

The remaining two dimensions make it possible to assess the system's capabilities in terms of communicative inclusion. Cognitive accessibility refers to the comprehensibility and usability of interfaces, while age-friendliness introduces a normative dimension linked to the explicit recognition of older adults in the communication architecture.

A review of the literature shows that these dimensions have been addressed in a fragmented manner, without an integrated framework that would allow them to be analyzed together in municipal communication contexts. Table 2 summarizes the main theoretical gaps identified and the specific contributions of this study.

Based on these dimensions, we propose an analytical model of digital communication sustainability that conceptualizes municipal communication as an integrated infrastructure that generates cognitive externalities. As shown in Figure 1, the model links the structural conditions of the information system, cognitive accessibility, and institutional orientation to the potential realization of public value through effective access, understandable service use, participation, and inclusion.

Table 2. Theoretical gaps and the article's contribution.

Field of study	Dominant focus	Limitation	Contribution of the article
Digital sustainability	Material- and energy-related externalities of digitalization	Limited attention to the informational and cognitive dimensions	Incorporates cognitive externalities as a component of urban sustainability
Digital governance and public value	Digital services, platform governance, orchestration, and public-value creation	Technological availability is often treated as a proxy for value, with limited attention to cognitive access conditions	Frames coherence, accessibility, and inclusive orientation as conditions for potential public-value realization
Age-friendly cities	Social inclusion and urban adaptation to aging	Limited development of the digital and communication dimensions	Integrates the age-friendly approach into the analysis of municipal digital infrastructures
Web usability and human–computer interaction	User-centered design and accessibility	Disconnection from the institutional context and public governance	Repositions cognitive accessibility within the scope of urban governance

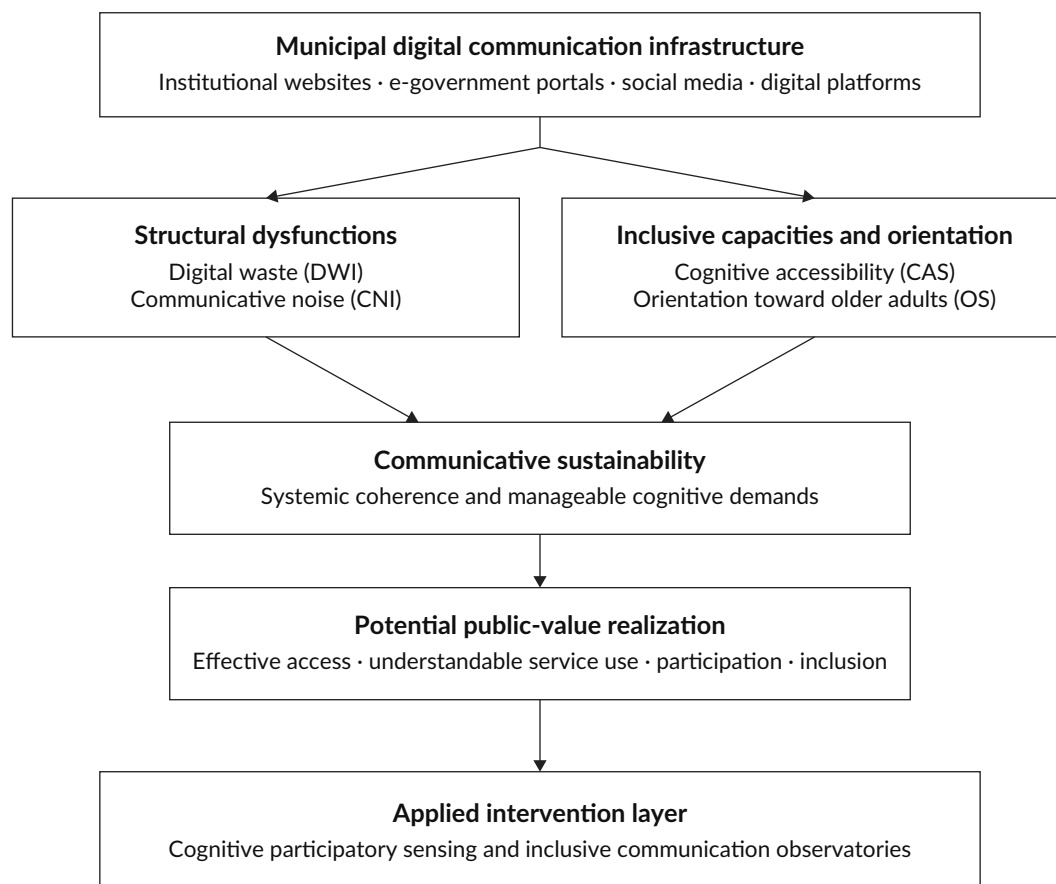


Figure 1. Analytical model of digital communication sustainability in municipal digital communication infrastructures. Notes: The model identifies enabling or eroding conditions; it does not posit direct causal effects.

Rather than positing direct causal relationships between observed variables, the model identifies structural conditions that may enable or erode access to, understanding of, and use of public information. It therefore provides a conceptual foundation for empirical diagnosis and for subsequent intervention strategies in local communication governance, while leaving user-experienced public value to be tested directly in future research.

3. Methodology

This study employs a comparative design based on systematic content analysis to examine the digital communication infrastructures of municipalities that are part of the Spanish Network of Age-Friendly Cities and Communities. This design operationalizes the two objectives stated above by identifying structural conditions of inefficiency and communicative capacity in municipal digital environments and examining how these conditions combine into distinct configurations.

3.1. Methodological Design and Analysis Logic

The study is based on a systematic content analysis of municipal digital ecosystems, designed as a structural diagnostic phase. Rather than directly assessing users' subjective experiences, this study evaluates the observable conditions of organization, accessibility, and coherence that shape access to public information and that can increase or reduce cognitive loads when using digital systems.

Content analysis is a well-established strategy for the systematic study of communication and has been adapted for the analysis of digital environments, enabling a comparative examination of information architecture, navigability, and the functionality of web interfaces (Herring, 2010; Krippendorff, 2018; Neuendorf, 2017). This study adopts a structural perspective aimed at identifying how the dimensions of the theoretical model are empirically reflected in municipal communication configurations.

3.2. Sample and Selection Criteria

The sample consists of 20 municipalities from the Spanish Network of Age-Friendly Cities and Communities, selected through purposive sampling in two autonomous communities (administrative regions): the Valencian Community ($n = 8$) and the Basque Country ($n = 12$). The selection was informed by a comparative approach aimed at maximizing analytically relevant variability, taking into account differences in population size, institutional history, the degree of implementation of the *age-friendly* model, and the complexity of municipal digital infrastructures (WHO, 2007).

The two regions offer variation without constituting a simple advanced-lagging contrast. The Basque Country has shown sustained progress across digital skills, infrastructure, business transformation, and public-service digitalization, although its relative performance remains mixed across dimensions (Franco et al., 2024). It also provides a regionally coordinated age-friendly framework through Euskadi Lagunkoia. The Valencian Community likewise displays extensive connectivity and continued development of digital public services, while official assessments still emphasize uneven use and the need to reduce digital gaps (Comité Econòmic i Social de la Comunitat Valenciana, n.d.). These different institutional trajectories and modes of coordination strengthen the comparative rationale while preserving a manageable and broadly

comparable scale. The aim is analytical generalization rather than statistical representativeness (Flyvbjerg, 2006; Yin, 2018).

Table 3. Municipalities included in the sample.

Municipality	Autonomous Community (Admin. Region)	Province	Network membership date	Project cycle and stage of development	Institutional website
Alcoi	Valencian Community	Alicante	2019–present	Cycle 1 (4)	https://www.alcoi.org
Elche	Valencian Community	Alicante	2018–present	Cycle 1 (2)	https://www.elche.es
Mutxamel	Valencian Community	Alicante	2023–present	Cycle 1 (4)	https://ayto.mutxamel.org
Castellón de la Plana	Valencian Community	Castellón	2014–present	Cycle 1 (4)	https://www.castello.es
Gandia	Valencian Community	Valencia	2018–present	Cycle 1 (1)	https://www.gandia.es
L'Eliana	Valencian Community	Valencia	2021–present	Cycle 1 (1)	https://www.leliana.es
Oliva	Valencian Community	Valencia	2017–present	Cycle 1 (1)	https://www.oliva.es
Valencia	Valencian Community	Valencia	2016–present	Cycle 1 (2)	https://www.valencia.es
Amurrio	Basque Country	Álava	2025–present	Cycle 1 (1)	https://www.amurrio.eus
Campezo	Basque Country	Álava	2017–present	Cycle 1 (2)	https://www.kanpezu.eus
Vitoria-Gasteiz	Basque Country	Álava	2011–present	Cycle 1 (2)	https://www.vitoria-gasteiz.org
Basauri	Basque Country	Bizkaia	2017–present	Cycle 1 (3)	https://www.basauri.eus
Bermeo	Basque Country	Bizkaia	2016–present	Cycle 1 (2)	https://www.bermeo.eus
Bilbao	Basque Country	Bizkaia	2011–present	Cycle 3 (3)	https://www.bilbao.eus
Durango	Basque Country	Bizkaia	2013–present	Cycle 1 (3)	https://www.durango.eus
Leioa	Basque Country	Bizkaia	2024–present	Cycle 1 (1)	https://www.leioa.net
Andoain	Basque Country	Gipuzkoa	2024–present	Cycle 1 (1)	https://www.andoain.eus
Donostia-San Sebastián	Basque Country	Gipuzkoa	2009–present	Cycle 3 (3)	https://www.donostia.eus
Eibar	Basque Country	Gipuzkoa	2017–present	Cycle 1 (2)	https://www.eibar.eus
Irún	Basque Country	Gipuzkoa	2017–present	Cycle 1 (2)	https://www.irun.org

Note: Values are reported as Cycle x (y), where x indicates the project cycle and y indicates the stage of development: (1) commitment letter, (2) baseline assessment, (3) strategy and action plan, and (4) evaluation. Source: WHO (n.d.)

3.3. Units of Analysis and Data Collection

The units of analysis are the municipal digital ecosystems structured around each city council's institutional website, which is considered the central node of digital public communication. The analysis covers the overall

structure of the website and how it is linked to other components of the system; specifically, the e-government portal, the institution's social media profiles, and the documents that can be accessed via the website.

The data were collected between January and February 2026 using a consistent protocol for the systematic observation and recording of URLs, access dates, and screenshots. This procedure made it possible to ensure the traceability of the analysis and to minimize, as far as possible, the effects of the volatility of digital environments.

3.4. Operationalization and Design of the Codebook

The theoretical dimensions of the model were operationalized using a structured codebook that translates analytical concepts into observable evidence. Developed from the literature reviewed and refined through a pilot phase, the instrument includes 102 analytical variables, binary, ordinal, count-based, and open-ended, organized around four dimensions: digital waste, communicative noise, cognitive accessibility, and information orientation toward older adults. Three additional fields record the case identifier (ID), municipality name, and URL.

The codebook was designed to capture both the structural properties of the communication system and institutional decisions regarding the information's organization and visibility. Open-ended variables were used for descriptive and contextual purposes, while the construction of indices was based on standardized, coded indicators. The full instrument, along with the operational definitions, coding criteria, and application examples, is available in the article's open repository (<https://doi.org/10.5281/zenodo.19467514>).

3.5. Coding Procedure and Reliability

The coding process was carried out in three phases: piloting of the instrument, full coding, and verification of intercoder reliability. Two coders independently analyzed the entire set of cases (20 municipalities) and analytical variables (102), resulting in 2,040 coding decisions. Twelve discrepancies were recorded, corresponding to an observed agreement of 99.41%. Cohen's kappa was 0.95, indicating almost perfect agreement (Landis & Koch, 1977). Because Cohen's kappa can be affected by unbalanced distributions in dichotomous variables, its interpretation was supplemented by observed agreement (Feinstein & Cicchetti, 1990). The discrepancies were reviewed jointly and led to specific adjustments to the operational definitions, strengthening the overall consistency of the coding process.

3.6. Index Construction and Analytical Strategy

The analytical strategy combines three levels: descriptive analysis of indicators, comparison between cases, and configurational analysis aimed at identifying recurring patterns. To this end, four composite indices were constructed corresponding to the dimensions of the model: the Digital Waste Index (DWI), the Communicative Noise Index (CNI), the Cognitive Accessibility Score (CAS), and the Orientation Score (OS).

These indices are formative synthetic measures in which the indicators define structural properties of the communication system (OECD & Joint Research Centre of the European Commission, 2008). Given heterogeneous measurement scales, all indicators were normalized to a 0–1 range before aggregation;

specifically, indicators RD1–RD4, coded from 0 to 2, were divided by 2. Missing values were excluded from index calculations, and an index score remained unavailable only when all constituent indicators for that index were missing. The indices use simple, unweighted arithmetic means to preserve transparency, avoid arbitrary weighting, and facilitate comparison in this exploratory diagnostic study.

The DWI and the CNI capture dysfunctional properties of the communication infrastructure, while the CAS and the OS enable the assessment of functional capacities and institutional information orientation. This differentiation is incorporated into both the interpretation of the results and the subsequent configurational analysis, which examines the combination of communicative dysfunction and communicative capacity at the municipal level. Table 4 summarizes the correspondence between analytical dimensions, observable evidence, indicators, and composite indices.

Table 4. Analytical dimensions, operationalization, and composite indices.

Dimension	Observable evidence in municipal settings	Indicators (codebook)	Index
Digital waste	Duplicate content, obsolete documents, broken links, redundant navigation structures	RD1–RD4	DWI
Communicative noise	Inconsistent terminology, incoherent navigation paths, fragmentation across institutional channels	FR1–FR3	CNI
Cognitive accessibility	Clear language, hierarchical structure, navigability, search tools, comprehension support resources	AC1–AC7; ACC9	CAS
Institutional orientation toward older adults	Age-friendly content on mobility, transport, housing, services, activities, and active ageing; institutional visibility; documentation; and contact and participation channels	ACC1–ACC7; DOC1–DOC6; CO1–CO46	OS

Note: The alphanumeric codes are variable identifiers from the codebook: RD = digital waste, FR = fragmentation and communicative noise, AC = cognitive accessibility and usability, ACC = municipal website structural accessibility, DOC = official documents and information resources, CO = content oriented toward older adults; full item labels, operational definitions, and coding rules are provided in the Supplementary File.

To ensure the traceability and replicability of the study, the article's open repository includes full details on the construction of the indices, the transformations applied to each variable, the calculation syntax, and the data matrix used in the analysis.

4. Results

4.1. Patterns of Digital Waste and Communicative Noise

Analysis of the DWI and the CNI reveals distinct patterns of inefficiency in municipal communication infrastructures. All 20 municipalities were included in the analysis, although valid index scores were available for 17 municipalities for the DWI and 18 for the CNI because, in three and two cases respectively, all constituent indicators for the relevant index were missing. The DWI has a mean of 0.33 ($N = 17$; range = 0–0.63), while the CNI has a mean of 0.41 ($N = 18$; range = 0–0.67), indicating a somewhat higher incidence of problems related to coherence, content presentation, and integration within the communication system.

An examination of the specific indicators (see Annex A in the article's open repository) provides further details on these trends. Regarding digital waste, the duplication of information is limited (17.6%), while the presence of broken links (50%), complex navigation paths (50%), and outdated documents (53.8%) stands out. These results suggest problems related to the accumulation and maintenance of content rather than explicit redundancy.

Communicative noise, on the other hand, exhibits a different pattern. Inconsistent terminology (11.8%) and the absence of feedback mechanisms (11.8%) have a low incidence, whereas incoherent navigation paths appear in 88.9% of cases, representing the main factor contributing to the fragmentation and dispersion of information aimed at older adults.

Overall, the results reveal two distinct patterns: Digital waste is concentrated in the obsolescence and accumulation of content, while communicative noise is manifested primarily in the disjointed nature of navigation paths. Furthermore, the comparative analysis reveals a high degree of heterogeneity among municipalities, with configurations that combine different levels of both dimensions.

4.2. Cognitive Accessibility and Information Orientation for Older Adults

The analysis of cognitive accessibility through the CAS and institutional orientation toward older adults through the OS allows us to assess the communicative capabilities of municipal digital systems. A selected set of indicators is presented in Annex A of the article's open-access repository.

The CAS has a mean of 0.34 ($N = 20$; range = 0–0.88), indicating uneven development of comprehensibility and navigability. This dimension is primarily supported by basic resources, such as the use of clear language and the availability of internal search engines. However, the prioritization of content, the consistent organization of menus, and resources to support comprehension (guides, tutorials, and audiovisual content) show limited levels of development.

The OS has a mean of 0.28 ($N = 20$; range = 0–0.58), indicating moderate-to-low development and fragmented coordination. Visibility for older adults is low, with a widespread lack of direct links from the main menu. Although some municipalities have dedicated sections or include content in their social services areas, these solutions do not represent a systematic organization of information.

At the institutional level, the availability of content related to active aging or age-friendly policies is uneven, and dedicated contact channels are not always integrated into coherent communication systems. Furthermore, the document dimension shows limited development. A comparison of the two dimensions reveals a significant asymmetry: Cognitive accessibility shows partial development of functional tools, whereas institutional orientation toward older adults is more limited and less systematic.

4.3. Configurational Analysis: Types of Municipal Communication Systems

To integrate the results, a configurational analysis was carried out based on two summary dimensions: (a) communicative dysfunction, defined as the mean of the DWI and the CNI, and (b) communicative capacity, defined as the mean of the CAS and the OS.

To apply a common reference frame, both cut-off points were calculated among the 17 municipalities with complete information on both summary dimensions. The resulting means are 0.350 for dysfunction and 0.360 for capacity. Municipalities below or above these thresholds are classified as advanced, basic, hybrid, or critical; cases lacking the dysfunction axis are reported separately as indeterminate. The resulting configurational map is shown in Figure 2.

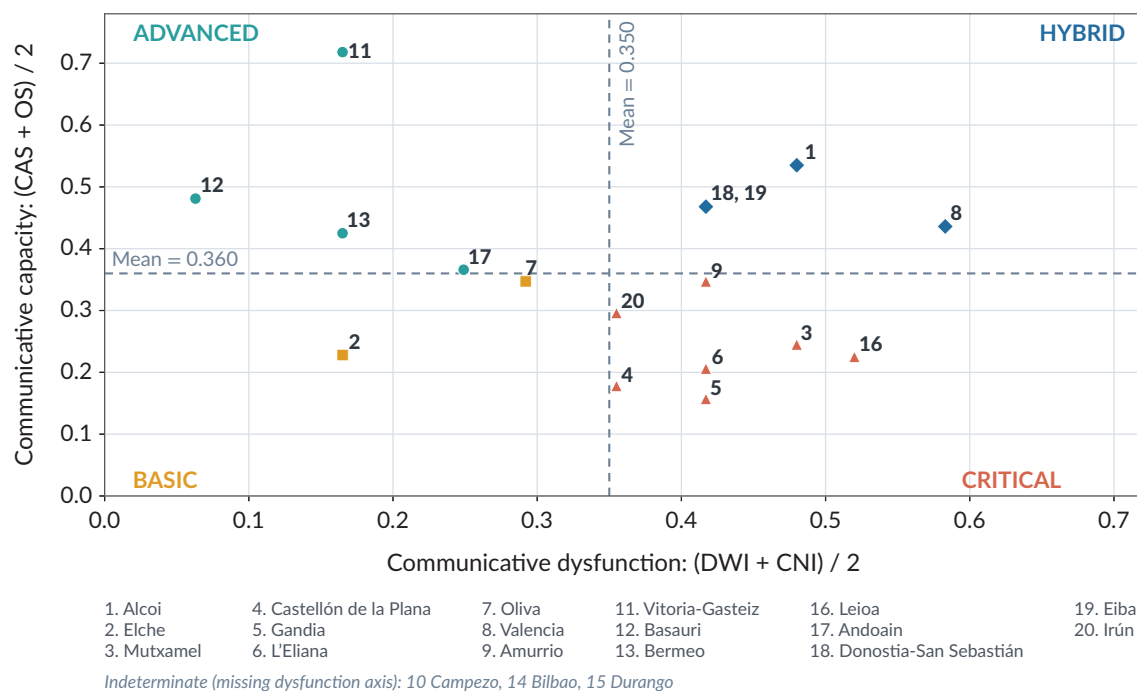


Figure 2. Configurational map of municipal communication systems.

Table 5 summarizes the resulting configurational typology, including the municipalities assigned to each type and their dominant traits.

Table 5. Configurational typology of municipal communication systems.

Type	n (%)	Municipalities	Dysfunction	Capacity	Dominant trait
Advanced	4 (20%)	Vitoria-Gasteiz; Basauri; Bermeo; Andoain	Low	High	High capacity with controlled dysfunction
Basic	2 (10%)	Elche; Oliva	Low	Low	Capacity shortfall despite limited dysfunction
Hybrid	4 (20%)	Alcoi; Valencia; Donostia-San Sebastián; Eibar	High	High	Coexistence of dysfunction and capacity
Critical	7 (35%)	Mutxamel; Castellón de la Plana; Gandía; L'Eliana; Amurrio; Leioa; Irún	High	Low	High dysfunction with limited capacity
Indeterminate	3 (15%)	Campezo; Bilbao; Durango	Not available	Varies	Missing data prevent configurational assignment

Notes: Classification uses the mean values among the 17 complete cases for both axes—communicative dysfunction = 0.350 and communicative capacity = 0.360; three municipalities lack sufficient information to calculate the dysfunction axis and are therefore classified as indeterminate.

The corrected distribution reveals substantial heterogeneity rather than a predominance of intermediate systems. Critical configurations form the largest group (7 of 20; 35%), followed by advanced and hybrid systems (4 cases each; 20% each) and basic systems (2 cases; 10%). Three municipalities (15%) are indeterminate because the dysfunction axis cannot be computed. Among the 17 classifiable cases, critical systems account for 41.2%, advanced and hybrid systems for 23.5% each, and basic systems for 11.8%.

The four hybrid configurations remain analytically important because they show that developed capacities can coexist with substantial structural inefficiency. Conversely, the critical group combines above-average dysfunction with below-average capacity. Together, these patterns demonstrate the heterogeneity of municipal communication infrastructures and the absence of a single consolidated model in the contexts analyzed.

5. Discussion

These results enable us to advance a reinterpretation of municipal digital communication as an urban infrastructure that generates cognitive externalities. This reformulation expands on the dominant approach to digital sustainability, which is typically focused on the material, energy-related, or infrastructural dimensions of digitalization (Belkhir & Elmeligi, 2018; Frenken & Schor, 2017; Martinez, 2023), and introduces a dimension that is less covered in the literature: the conditions under which digital systems organize access to, understanding of, and use of public information. From this perspective, municipal digitalization cannot be assessed solely based on the availability of resources, services, or channels, but also based on the type of information environment it creates and the cognitive load it places on citizens.

On this point, the study's findings suggest that communication inefficiencies do not stem primarily from the amount of information available, but rather from the way that information is organized and presented within the system. The prevalence of inconsistent navigation paths, the continued existence of outdated documents, and the fragmentation of information across components of the municipal digital ecosystem indicate that a significant portion of the cost of digitalization is not only infrastructural, but also cognitive. This finding is consistent with the literature on information overload, which has shown that an increase in digital content does not necessarily improve users' processing capacity and may, on the contrary, make it more difficult for them to orient themselves and make decisions in complex environments (Bawden & Robinson, 2009; Eppler & Mengis, 2004). When applied to the municipal context, this means that part of the work of rebuilding the system's institutional architecture falls to the public, making access to public information a more costly and uncertain process than conventional digitalization indicators suggest.

This interpretation also clarifies how municipal digital environments may either generate or fail to generate public value. Public value cannot be inferred from the mere presence of portals, services, or channels; it depends on whether institutional arrangements convert digital capabilities into outcomes that citizens can effectively use and value (Cordella & Bonina, 2012). Platform orchestration is therefore central: Coordination among interfaces, services, and actors can support coherent access and co-creation, whereas fragmentation transfers integration work and cognitive cost to users (Cordella & Paletti, 2019; Mersico et al., 2026). The four dimensions examined here should thus be read as observable conditions for potential public-value realization, not as direct measures of its experienced outcomes.

One of the article's most significant contributions lies in its configurational analysis. The dimensions do not operate in a linear or simply cumulative manner but combine into distinct typologies. Advanced systems show that low dysfunction and high capacity can coexist, while hybrid systems combine developed capacities with persistent structural strain. The largest group is critical, with above-average dysfunction and below-average capacity. This distribution challenges an instrumental view of public innovation that associates improvement with accumulating channels, tools, and functionalities (Bannister & Connolly, 2011; Bertot et al., 2010). Communication quality instead depends on the coherence and effectiveness with which resources are integrated into a navigable and understandable architecture.

The relevance of this finding becomes even more significant when interpreted in the context of the literature on age-friendly cities and communities. The WHO (2007) identified communication and information as one of the eight structural domains of age-friendly cities and communities. However, subsequent literature has pointed out that the digital dimension of this domain remains underdeveloped and that many systems continue to be designed based on assumptions of a homogeneous user population, which perpetuates inequalities in information access and use (Kolotouchkina et al., 2023; Neves et al., 2018; Seifert, 2020). The results obtained reinforce this critical perspective. Institutional focus on older adults is moderate or fragmented, and while there have been some functional improvements in cognitive accessibility, these have not been accompanied by a more comprehensive overhaul of the communication architecture.

This brings us to one of the study's most significant findings: the tension between cognitive accessibility and institutional orientation toward older adults. In several cases, the institutional visibility of this group does not translate into robust conditions for understanding, navigating, or using information. This disconnect confirms that focusing on a stakeholder group cannot be reduced to its symbolic presence on the institutional interface. It also requires a material and cognitive structuring of the information environment. From this perspective, the focus on older citizens serves as the normative dimension of the model, while cognitive accessibility constitutes its functional one. The gap observed between the two dimensions reduces the inclusive potential of municipal communication and suggests that digital friendliness depends not only on recognizing specific audiences, but also on reorganizing the system so that this recognition is operationally effective.

This interpretation also allows us to further refine the concept of the structural inefficiency of municipal communication. Throughout the empirical analysis, we have used the concept of communicative dysfunction to refer to digital waste and communicative noise as observable manifestations of system problems. However, the results suggest that these dysfunctions should be understood as reflecting a flawed structural relationship between information organization, system coherence, and the potential user experience. This formulation expands on the traditional approach to web usability, which typically focuses on the technical or interactional properties of the interface (Czaja et al., 2006; Norman, 2013; Sayago & Blat 2011) and situates it within the field of digital urban governance. As a result, communicative quality is no longer solely a matter of design or functionality, but rather becomes an institutional attribute of the public information system.

Based on this, we can identify a second contribution of the article: the need to incorporate a meta-evaluative dimension into the analysis of institutional communication. Much of the literature on digital government and age-friendly cities has focused on services, content, or outcomes, but fewer tools have been developed to comparatively assess how communication infrastructures themselves create barriers,

inconsistencies, and access costs. In this regard, the study not only identifies empirical shortcomings, but also highlights a meta-evaluative one in the way local institutions monitor, diagnose, and review their digital communication systems. The problem lies not only in the existence of communication barriers, but also in the lack of sufficiently integrated frameworks to identify these barriers as systemic configurations rather than as isolated failures.

It is at this point that what we term cognitive participatory sensing acquires particular conceptual relevance. Although it is not implemented empirically in this study, we use the term to describe a possible extension of participatory urban sensing to the identification and interpretation of cognitive barriers in municipal digital communication. Participatory urban sensing enables citizens to contribute locally situated information to municipal systems, including by reporting conditions and problems in urban infrastructures (Winkler et al., 2012), while the broader literature on volunteered geographic information conceptualizes citizens as active sensors whose observations can complement conventional information sources (Goodchild, 2007). Applied to municipal communication, this means recognizing older adults not only as potentially vulnerable users of complex systems, but also as agents capable of generating situated knowledge about access barriers, inconsistencies, and cognitive friction points. From this perspective, the configurations identified in the study can be seen as a preliminary diagnostic foundation for developing participatory, structured evaluation processes.

Initiatives such as URBANAGE have explored the use of urban digital twins, age-friendliness indicators, and participatory mechanisms to model the impact of interventions on accessibility, safety, and the distribution of services (European Commission, 2021; Urra-Urriarte et al., 2024). Similarly, initiatives such as City&Co have combined assessment tools, geospatial data, and participation by older adults and technical staff to assess the age-friendliness of neighborhoods and inform local decision-making (JPI Urban Europe, 2022). Although these developments operate at partially different scales and address partially different issues, they show that digital technologies can be leveraged not only to optimize physical infrastructure, but also to shed light on the conditions that shape urban aging. The specific contribution of this article is to shift this focus to municipal digital communication, proposing that the assessment of communication externalities can be integrated into broader agendas for age-friendly urban planning.

Within this framework, inclusive communication observatories (Campillo-Alhama & Mateo-Perez, 2026) represent a particularly relevant initiative. The results point to the need for mechanisms that can translate the analytical diagnosis of communication infrastructures into collaborative processes of observation, feedback, and intervention. The existence of hybrid systems particularly underscores this need. Where developed capacities coexist with persistent dysfunctions, improvement does not seem to depend solely on technical solutions, but rather on participatory mechanisms that make it possible to identify internal contradictions, prioritize problems, and guide processes for redesigning institutional communication. From this perspective, observatories do not appear as an external addition to the model, but rather as a possible applied extension of a structured and situated evaluation logic.

Digital communication sustainability should be understood as an emergent attribute of urban information infrastructures. It depends not only on the existence of digital resources, but also on structural coherence, the reduction of cognitive loads, and effective orientation toward specific groups. These conditions can enable or erode the realization of public value through access, service use, participation, and inclusion.

The article's contribution is an analytical framework that describes and compares these conditions empirically while avoiding the stronger claim that public value itself has been directly measured.

6. Conclusion

This study has examined municipal digital communication as an urban infrastructure from the perspective of communication sustainability, proposing an analytical model based on four dimensions: digital waste, communicative noise, cognitive accessibility, and institutional orientation toward older adults. Based on a comparative analysis of municipalities, the results show that communication inefficiencies do not follow a single pattern, but rather result from distinct configurations in which the organization of information and the coherence of the system are decisive.

In particular, the analysis shows that communication quality does not depend solely on the availability of resources or channels, but on how they are integrated into coherent and cognitively accessible information structures. The distinction between digital waste and communicative noise makes it possible to identify different forms of inefficiency, while the relationship between cognitive accessibility and institutional orientation shows that communication inclusion requires the convergence of the functional and normative dimensions.

The configurational analysis supports this interpretation by identifying distinct combinations of dysfunction and capacity. The largest group combines above-average dysfunction with below-average capacity, while advanced and hybrid cases each form a substantial minority. Improving communication therefore cannot be understood as accumulating resources; it requires systemic coherence and institutional orchestration.

From a theoretical perspective, this article contributes to expanding the field of digital sustainability by incorporating the informational and cognitive dimensions of digitized urban systems, and to strengthening the conceptualization of municipal communication as a governance infrastructure. This approach makes it possible to link the evaluation of digital environments to discussions on inclusion, participation, and age-friendly cities.

The study has limitations stemming from the size and purposive nature of the sample, as well as the lack of direct user-experience data, which limits causal and outcome-based inference. Future research should extend the analysis to larger samples and test the relationship between the configurations identified and experienced public-value outcomes, such as effective service use, trust, or civic participation. It should also examine how AI-enabled search, conversational assistance, summarization, and personalization may reduce cognitive effort, while opacity, variable outputs, overconfidence, synthetic content proliferation, and unequal digital skills may redistribute or intensify cognitive load (OECD, 2025). Participatory evaluation approaches such as cognitive participatory sensing offer a promising means of linking structural diagnosis to the improvement of local communication governance.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The data supporting the findings of this study are deposited in Zenodo at <https://doi.org/10.5281/zenodo.19467514>. The repository includes the full dataset, the operational codebook, and the SPSS syntax used for index construction and analysis. These materials enable full replication of the analytical procedures described in the article.

LLMs Disclosure

The authors used ChatGPT (OpenAI, GPT-5 architecture) as a research and writing support tool. The LLM was employed to assist with language editing, translation from Spanish into academic US English, stylistic refinement, and structural clarification of arguments. During an early exploratory phase of the study, it was also used to assist with literature searching and bibliographic organization. Bibliographic suggestions generated during this phase were treated as provisional inputs requiring author verification. All conceptual development, theoretical framing, interpretation of sources, and final content decisions were conducted and validated by the authors. The authors assume full responsibility for the accuracy, integrity, and originality of the manuscript.

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