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Transparency as a Dynamic Capability in People-Centered Smart Cities: A Maturity Model from the Netherlands

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Abbreviations

IoT	Internet of Things
TMM	Transparency Maturity Model
IoT-TMM	Internet of Things-Transparency Maturity Model
PCSC	People-Centered Smart Cities
GUI	Graphical User Interface
SME	Subject Matter Expert
NLP	Natural Language Processing
TET	Transparency-Enhancing Tool
PET	Privacy-Enhancing Tool
GQO	Goal-Question-Operationalization
SaaS	Software-as-a-service

1 The Growing Anxiety: Why Smart Cities Struggle and How Transparency Can Help

Smart cities promise a transformative approach to urban living through advanced technologies (Bastos et al., 2022; Valenzuela-Aguilera et al., 2024). However, the path to realizing this potential is paved with challenges. Numerous initiatives have encountered significant public resistance or outright abandonment, often stemming from deep-seated concerns about privacy and transparency.

The tale of Sidewalk Labs' Toronto Waterfront Project is a vivid example of when the promise of smart cities meets with public distrust and privacy concerns. In 2020, Sidewalk Labs' ambitious plan to transform Toronto's waterfront into a data-driven neighbourhood "smart city" powered by Internet of Things (IoT) collapsed largely due to widespread public distrust fueled by anxieties over data collection and potential surveillance. This resistance was vocal and visible, even manifesting in online movements like the #BlockSidewalk campaign, which captured widespread anxiety and opposition to the project. The goal was to create a city of the future, equipped with smart infrastructure that would optimize everything from transportation to waste management. Yet, despite the allure of cutting-edge technology, the project faced intense public backlash. Privacy advocates raised alarms about the vast amount of personal data the project would collect from residents, arguing that it could lead to an unprecedented level of surveillance. Media and civil society groups raised alarms about the risk of personal data falling under foreign legal regimes, however, the company (Sidewalk Lab) failed to provide adequate public reassurance (Mann et al., 2020; Shimizu et al., 2022). This incident is not isolated; A broader pattern of public resistance has emerged in response to various smart city initiatives worldwide.

In Hong Kong, the public reacted strongly and violently against the installation of smart lamp posts, perceiving them as tools of state surveillance amidst broader geopolitical tensions. The destruction of these lamp posts underscored the profound anxiety surrounding privacy and freedom in a technologically mediated urban environment (Mann et al., 2020). Similarly, Jameson et al.'s (2019) study of Amsterdam's smart city programs revealed that many residents felt surveilled, leading to coping mechanisms aimed at resisting or circumventing sensor-based monitoring, by avoiding specific smart infrastructure altogether (Jameson et al., 2019). These instances highlight a fundamental distrust in opaque technological mediation and fears about the potential misuse of collected data, particularly when its purpose and handling are unclear to citizens (Jameson et al., 2019; Mann et al., 2020; Shimizu et al., 2022).

To understand people's responses to datafication, Ditchfield et al. (2024) introduced the concept of "data imagining," the mental process through which individuals anticipate how their data might be used or misused in the future. This anticipatory reflection, characterized by "what if" questions, allows for critical engagement with data practices, shaped by existing knowledge and experiences. Complementing this cognitive dimension, Pink et al. (2018) explored the emotional landscape of datafication, coining "data anxieties" to describe the fears arising from the unpredictable future of data. Conversely, "data trust" emerges as a crucial countermeasure, built through familiarity, transparent practices, and perceived security (Pink et al., 2018). Our interview findings corroborate this dynamic. As one participant noted, initial strong public opposition to environmental sensors, driven by surveillance concerns, significantly decreased once authorities clearly communicated that the sensors' sole purpose was to monitor air quality for public health improvements. This shift underscores that clarity of intended use is not merely a regulatory requirement but a vital strategy for building trust and fostering citizen engagement.

This anxiety is particularly pronounced concerning what Keenan (2009) terms "silent information"—person-linked data deliberately collected and distributed without the subject's explicit understanding and consent to its full range of uses. This form of passive data collection raises fundamental concerns about the adequacy of traditional consent mechanism and necessitates new mechanisms grounded in genuine and tailored transparency for smart cities (Keenan, 2009).

Smart cities aim at optimizing infrastructure, enhancing public services, and promoting citizen well-being by integrating advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics (Bastos et al., 2022; Valenzuela-Aguilera et al., 2024). At the heart of this transformation lies the IoT (Chanson et al., 2019; Colli et al., 2021; Long et al., 2024). The IoT market, for instance, has expanded significantly —growing from $761.4 billion in 2020 to an anticipated value exceeding $1 trillion in 2025 (Long et al., 2024). Yet, despite the benefits, the aforementioned examples illustrate a growing public anxiety surrounding the often-opaque data practices and inconsistent accountability measures (Long et al., 2024), which pose significant challenges to realizing the full potential of IoT-enabled environments (European Court of Auditors, 2023).

In this study, the terms "IoT systems" and "sensors" are used interchangeably to refer broadly to the vision of networked infrastructure of devices, processes, and platforms responsible for data collection and processing in urban environments (Chanson et al., 2019). While there is a technical distinction—sensors being the physical devices that capture specific environmental or behavioral signals, and IoT systems comprising a broader architecture that includes sensors, networks, middleware, analytics, and applications (Chanson et al., 2019; Colli et al., 2021) —this paper adopts a pragmatic focus. Specifically, it emphasizes the outcome of these technologies: the collection of data that informs governance in smart city contexts. Accordingly, the use of "sensors" and "IoT systems" throughout the paper reflects their shared role in enabling urban datafication rather than adhering strictly to engineering classifications. This choice aligns with the study's central concern of the transparency of the privacy policies—regardless of the precise technological architecture involved.

The very definition of a smart city has also evolved over time (David et al., 2015). The concept of the 'sensor city' has emerged as a response to the challenges of growing datafication enabled by IoT systems (D'Amico et al., 2020). Historically, the term 'Smart City" had been used to describe and prioritize a technology-driven method (TDM) to urban planning, focused on ICT infrastructure and automation, this approach has been criticized for enabling private-sector dominance and undermining democratic control (Chanson et al., 2019); over time, a human-driven method (HDM) and People-Centered Smart City (PCSC) paradigm, championed by UN-Habitat, have emerged. These frameworks place participatory governance, citizen rights, and well-being at the core of smart cities (Calzada, 2020; Calzada et al., 2023; Di Bernardo et al., 2023; Kummitha & Crutzen, 2017; Mupfumira et al., 2024). Jakonen (2023) argues that meaningful smart city development requires the integration of "hard" technical infrastructure, such IoT systems and digital platforms, with "soft" social infrastructure, including civic innovation, digital literacy, and co-governance, to empower citizens to actively shape their urban environment.

Transparency, thus, emerges as a foundational principle in the PCSC paradigm — enabling public oversight over sensors deployments, data collection, and use, thereby fostering institutional accountability and public trust (Bastos et al., 2022; Calzada, 2020; Janssen et al., 2017; Long et al., 2024; Valenzuela-Aguilera et al., 2024). This emphasis on transparency is further reinforced by regulatory frameworks such as the General Data Protection Regulation (GDPR), which positions transparency as a strategic tool for shaping public perception and trust. In particular, Articles 5 and 13 of the GDPR mandate that data subjects must be informed in clear, accessible language about the purposes and scope of personal data processing (Houser & Bagby, 2022; Murmann & Fischer-Hubner, 2017; Urquhart et al., 2019).

In smart cities, where large-scale data collection is often embedded in public infrastructure (D'Amico et al., 2020), failure to provide such clarity may cause even wellintentioned projects to be perceived as opaque, intrusive, or manipulative. This reinforces the argument that transparency must go beyond mere compliance to become a proactive and participatory practice—one that enables informed public debate and enhances democratic legitimacy in data-driven urban governance.

Thus, this paper focuses on *ex ante transparency*—the proactive communication of intended data practices before any processing occurs—as a crucial response to the crisis of trust in datafied cities, with the aim to **develop a practice-oriented maturity model that supports municipalities assess, operationalize, and institutionalize transparency in people-centered smart cities.** To address this aim, we introduce the IoT Transparency Maturity Model (IoT-TMM), a multidimensional construct encompassing Accessibility, Usability, Informativeness, Understandability, Auditability, and Learnability. Recognizing that the implementation of transparency initiatives often suffers from fragmented ownership and a lack of institutional embedding (Bundgaard & Borrás, 2021; Matta et al., 2025; Interviews), the model aims to offer actionable insights for cities, urban planners, and technology providers to assess and enhance their transparency practices in alignment with GDPR, ultimately, fostering citizen trust, reducing resistance, and supporting the development of people-centered smart cities.

The remainder of the paper is structured as follows: *Chapter 2* presents a comprehensive literature review, beginning with a deconstruction of transparency as a contested concept followed by a reconstruction through theoretical and practical lenses, synthesizing the contouring qualities of transparency, ending by exploring the promise and limitations of Transparency-Enhancing Technologies (TETs). *Chapter 3* outlines the methodology, using a Design Science Research (DSR) framework. It explains the problem and requirements identification process via literature review and expert interviews, followed by the design and development of the proposed model using tools such as Goal-Question-Operationalization (GQO) and McKinsey's 7S model. *Chapter 4* details the design and development of the IoT-TMM, describing its five maturity levels, as well as its core dimensions and practices. *Chapter 5* presents the results of the model's validation and refinement through expert feedback and preliminary case studies from Amsterdam, The Hague, and the province of Brabant. *Chapter 6* concludes with the main contributions to theory and practice, limitations, and directions for future research and implementation.

2 Literature Review

2.1 Deconstructing Transparency: Beyond a "Magic Concept"

Transparency is frequently prescribed as a cornerstone of democratic governance—invoked by governments, civil society, and international organizations to signal openness and accountability; Yet despite its rhetorical appeal, transparency remains semantically ambiguous and operationally vague (Vakarelov & Rogerson, 2020). Scholars warn that the concept has become a "magic word" in governance discourse—widely celebrated but inconsistently defined or practiced (Grimmelikhuijsen et al., 2013; Matheus & Janssen, 2020; Matheus & Janssen, 2015). This section unpacks the contested nature of transparency by clarifying its relationship to neighbouring concepts, outlining its multidimensional character, and exposing its paradoxes in practice (Fox, 2007; Janssen et al., 2017; Matheus & Janssen, 2020; Matheus & Janssen, 2015; Vakarelov & Rogerson, 2020).

Transparency is not Openness

While the two is often used interchangeably, particularly in domains such as open government data, open-source technologies, and open science, openness and transparency are not synonymous (Larsson & Heintz, 2020; Matheus & Janssen, 2015).

Openness refers primarily to the availability of data, whereas transparency requires structured, purposeful communication that enables public understanding and oversight (David et al., 2015; Larsson & Heintz, 2020; Matheus & Janssen, 2015). Simply releasing datasets—no matter how comprehensive—does not guarantee transparency if the information lacks interpretability, context, or usability. The risk of "data dumping", or what Florini (2000) calls the "white noise effect," can obscure more than it reveals (Lnenicka & Nikiforova, 2021). A government, for example, may release vast quantities of data, yet if the information lacks clarity, structure, or direct relevance to public concerns, transparency remains unachieved.

While openness is a necessary precondition, it is not sufficient for achieving meaningful transparency (Larsson & Heintz, 2020; Matheus & Janssen, 2015). Thus, transparency's value lies in enabling informed action, requiring the timely, correct, and usable communication of information, and in facilitating accountability by making governmental actions observable and contestable (Albu & Flyverbom, 2019; David et al., 2015; Matheus & Janssen, 2015).

Transparency is not Accountability either

Closely linked to this discussion is the relationship between transparency and accountability. Transparency is a crucial tool in enabling accountability, however, full transparency is not always necessary for accountability; rather, sufficient information for informed evaluation is key (Matheus & Janssen, 2015). Transparency provides the essential raw material—accessible information—while accountability entails the active use of this information to evaluate performance, attribute responsibility, and potentially enforce consequences (David et al., 2015; Matheus & Janssen, 2015). Therefore, transparency and accountability are distinct yet interdependent concepts (Matheus & Janssen, 2015).

Thus, transparency, accountability, and openness are closely intertwined and mutually reinforcing, yet remain conceptually distinct. Transparency, is best understood as an instrumental tool rather than an end in itself (Heald, 2006); a mechanism for democratic accountability, by enabling the "ruled" to "observe" the "rulers" (Heald, 2006a, 2006b). According to this definition, transparency aims to equip citizens with the information needed to oversee government actions. However, to fulfil this, information must be "openly available" and "easily accessible" to the individuals impacted by public decisions (Pernagallo & Torrisi, 2020).

Dimensions and Directions of Transparency

According to Heald (2006a), transparency is also multi-directional: *inward* transparency enables external stakeholders to scrutinize internal governmental operations, whereas *outward* transparency facilitates feedback and oversight from the public (Matheus & Janssen, 2015). However, a deeper impediment to effective transparency is information asymmetry, wherein governments possess significantly more information than the public, restricting citizens' ability to oversee policies or hold officials accountable (Matheus & Janssen, 2015).

Grimmelikhuijsen and Welch (2012) offer a more structured lens for transparency. They distinguish between three interrelated components: *inward observability*, *active disclosure*, and *external accessibility*. Inward observability refers to the capacity of external actors—such as citizens, civil society organizations, or oversight bodies—to monitor the internal processes and decision-making activities of an organization. Active disclosure captures the extent to which an organization "proactively" releases relevant information about its operations, decisions, or data practices. External accessibility, in turn, denotes an organization's receptiveness to external evaluation and critique, reflecting its willingness to be held accountable (Grimmelikhuijsen & Welch, 2012). Accordingly, Grimmelikhuijsen and Welch, (2012) define transparency as:

> "the disclosure of information by an organization that enables external actors to monitor and assess its internal workings and performance"

To explore the multidimensionality of transparency, encompassing both *ex ante* and *ex post* dimensions. *Ex ante transparency* refers to the proactive communication of intended data practices—what data will be collected, for what purposes, and how—*before* any processing occurs; This is commonly implemented through privacy policies. In contrast, *ex post transparency* provides retrospective reporting and insights into—what data was actually collected, by whom, and whether it aligned with stated purposes, and who accessed it (Heald, 2006a; Zimmermann, 2015).

Critiques and Paradoxes of Transparency

Despite normative appeal, transparency does not always produce the intended outcomes. A critical challenge lies in the assumption that transparency inherently drives desirable behaviours and outcomes (Grimmelikhuijsen et al., 2013; Sarikakis, 2008). scholars such as Sarikakis (2008) and Fox (2007) offered a more cautionary perspective, arguing that transparency does not automatically translate into greater democracy or accountability (Fox, 2007). In practice, transparency can generate unintended or paradoxical consequences, such as increased confusion, mistrust, or information overload, particularly when information is poorly organized or inadequately contextualized (Larsson & Heintz, 2020; Matheus & Janssen, 2020; Matheus & Janssen, 2015). Moreover, transparency can be strategically deployed as a tool for obfuscation rather than clarification. As Florini (2000) cynically observed:

> *"If you really want to hide information, the best thing to do is to bury it in a flood of data "*

Despite the various theoretical lenses, a fundamental practical challenge remains: Information presented in outdated formats, technical jargon, or overwhelming volume ultimately fails to fulfill transparency's core purpose of empowering understanding and action. Albu and Flyverbom (2019) critique the rationalist assumption underlying many transparency initiatives—namely, that increased disclosure inherently enhances governance through validation and oversight. They contrast this *verifiability lens* with a *performativity approach*, which questions whether more information necessarily leads to better conduct. As Grimmelikhuijsen and Welch (2012) argue, clarity, defined as the extent to which disclosed information can be quickly understood, is crucial for the performance and outcome of transparency. They further caution against "pseudo transparency," where organizations appear transparent by publishing vast amounts of incomprehensible information online, potentially creating a "flood of misinformation"

This critique is echoed by Fox (2007), Matheus and Janssen (2015), and Ortega-Rodríguez et al. (2020), who argue that many transparency initiatives fall short as they stop at data publication without ensuring that the information is of sufficient quality, structure, and relevance to truly enable oversight (Fox, 2007; Matheus & Janssen, 2015; Ortega-Rodríguez et al., 2020). In a similar vein, Weil et al. (2013) advocate for *targeted transparency*, emphasizing that strategic and selective disclosure—rather than broad, indiscriminate openness—can be more effective in reducing risks and improving organizational performance.

This paradox highlights the persistent difficulty in operationalizing transparency due to its wide-ranging applications across different objects, uses, technologies, and practices (Larsson & Heintz, 2020).

2.2 Reconstructing Transparency: Related Models

Recognizing the challenges and paradoxes associated with transparency, scholars have proposed a range of frameworks and models to better conceptualize transparency.

One influential contribution is the transparency maturity model by Cappelli et al. (2013), which draws inspiration from the Capability Maturity Model Integration (CMMI) used in software engineering. Their model organizes transparency development along a five-stage: ranging from fundamental opacity to disclosure, comprehension, reliability, and ultimately participative engagement. This progression highlights that transparency is not a binary condition but a dynamic and evolving capability. Importantly, Cappelli et al. (2013) stress the necessity of moving beyond mere data publication toward fostering environments where stakeholders can reliably interpret and act upon information. Their framework conceptualizes transparency as an outcome, rather than a fully operationalized tool, assessed across dimensions such as informativeness, auditability, and usability. It serves as a roadmap for organizations to reflect on and enhance their transparency practices, though it stops short of operationalizing them.

A chronological examination of the transparency frameworks developed by Matheus and Janssen reveals a clear progression—from an inward, process-driven orientation to a more outward-facing, user-centered, and adaptive approach. This evolution reflects a growing recognition that transparency is not simply about internal data management but also about enabling meaningful public engagement through iterative, responsive and dynamic practices—what Teece (2016) frames as dynamic capabilities: the ability to sense, seize, and transform in response to a changing environment.

A complementary, yet inward-facing approach is the BOLD Transparency Framework, developed by Matheus and Janssen (2015), offers a granular system-oriented view of transparency by identifying key decision-making points in the design of transparency systems—ranging from the type of data disclosure, technology used, type of storage to analysis and visualization. As illustrated in Figure 1, the BOLD model outlines three core stages: data collection (from sources such as internal databases and documents), data storage and management (requiring specialized infrastructure), and data analysis and visualization. The model draws attention to two critical stakeholders—data publishers and users—who often operate without full awareness of each other's needs and face distinct challenges. Crucially, BOLD framework conceptualizes transparency as the emergent result of two interdependent processes: Data Disclosure and Data Usage, which collectively shape how transparency is enacted and perceived by various stakeholders. The first dimension, Data Disclosure, concerns the mechanisms through which data is made public. It includes the type of data disclosed (e.g., raw or aggregated), the channels used for dissemination (such as APIs or portals), the technologies supporting disclosure, and the characteristics of the data itself—such as its granularity, metadata, and accessibility. The second dimension, Data Usage, focuses on how and by whom the data is used. It considers the types of users (publishers and users), their motivations (accountability, innovation, etc.), the business or institutional models behind data use, and the technologies employed to analyze and apply the data. The third dimension, Transparency, emerges from the interaction between disclosure and usage. It is interpreted either as accountability—emphasizing oversight and control—or as openness, highlighting accessibility, participation, and trust (Matheus & Janssen, 2015).

According to Matheus and Janssen (2015), effective transparency emerges from the alignment of technological, institutional, and user-related factors with the specific goals and contextual conditions of a given initiative. This perspective laid the groundwork for what they later conceptualized as the “Window Theory”, developed in response to the unintended and potential paradoxical consequences of transparency initiatives (discussed in Section 2.1). The Window Theory offers a structured account of the diverse determinants and their relationship to transparency outcomes (Matheus & Janssen, 2020).

Metaphorically framed as a "window" into government activity, the theory posits that data alone is not enough to produce transparency—it is the frame (comprising system and organizational quality) and lighting conditions (user literacy and access) that determine whether the data becomes visible and usable. The theory identifies 42 determinants, grouped into four interrelated clusters—data quality, system quality, organizational characteristics, and individual characteristics. These factors interact to shape eight potential outcomes of transparency, including accountability, trust, participation, and efficiency, among others (Matheus & Janssen, 2020). This suggests that not all transparency roads lead to trust, and the form of transparency outcome needed is very dependent on multiple variables.

Therefore, the Window Theory highlights that transparency is contingent on a complex configuration of enablers such as system usability, performance, user literacy, political will, and contextual readiness. For instance, a highly sophisticated dataset may enhance transparency for a data-savvy analyst but remain opaque to a layperson unfamiliar with the platform or analytical tools. Thus, the theory conceptualize transparency as an emergent, context-sensitive, and gradual construct—more continuous than dichotomous (Matheus & Janssen, 2020; Matheus & Janssen, 2015).

This view of transparency is echoed by David et al. (2015), who frame it as part of a broader socio-technical ecosystem. Their model highlights the interdependence between technological investments (e.g., ICT infrastructure), societal capacity-building (e.g., digital literacy), and participatory governance mechanisms. In this view, transparency both supports and is supported by inclusive, participatory processes—suggesting that effective transparency requires more than open data; it depends on an enabling institutional and civic environment. This broader framing complements the Window Theory, which emphasizes the importance of the lighting conditions: contextual readiness, literacy, and usability.

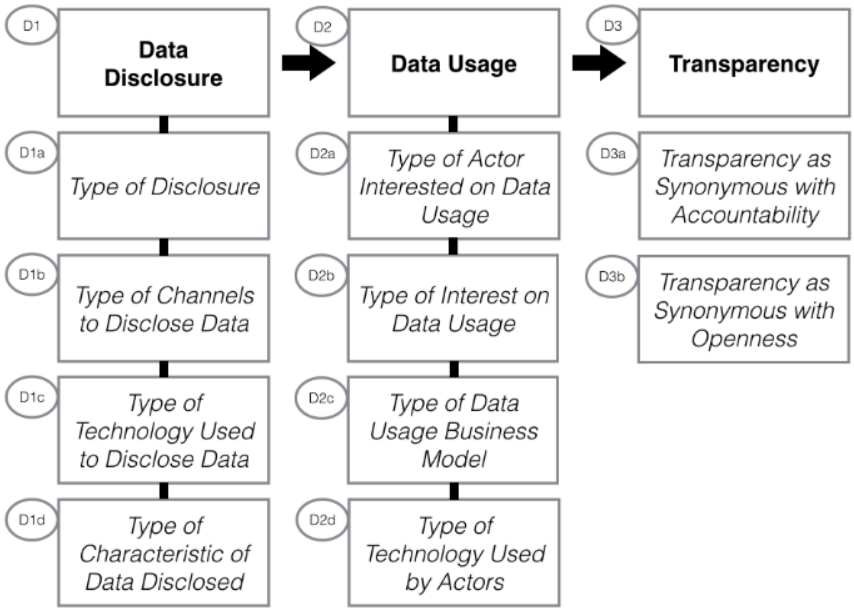

Figure 1: BOLD Framework by Matheus and Janssen (2015)

Building on this foundation, the Data-Driven Transparency Cycle Matheus et al. (2021) introduces a more explicitly iterative and participatory model that positions transparency as a public-facing, ongoing process. As illustrated in Figure 2, the cycle consists of six iterative phases: eliciting data need, collecting data, publishing data, using data, sharing results, and determining actions, where the early stages—particularly eliciting data needs and defining collection practices— invite organizations to "sense" societal expectations and informational gaps and offer opportunities for proactive communication about intended data uses, while the latter phases—such as sharing results and determining actions— reinforce accountability through feedback and adaptation of internal routines and processes—thus enabling the “seize” and “transform” stages of Teece's (2016) “dynamic capabilities” concept.

Similarly, Weil et al.'s (2013) notion of “targeted transparency” reinforces the point that transparency must be purposeful to meet the public need and lead to meaningful behavioral responses to fulfill its democratic and governance potential. Their “action cycle” model conceptualizes transparency as a cycle that also includes information provision, use, and response- similarly posits that the mere provision of information is insufficient unless it leads to observable behavioral change.

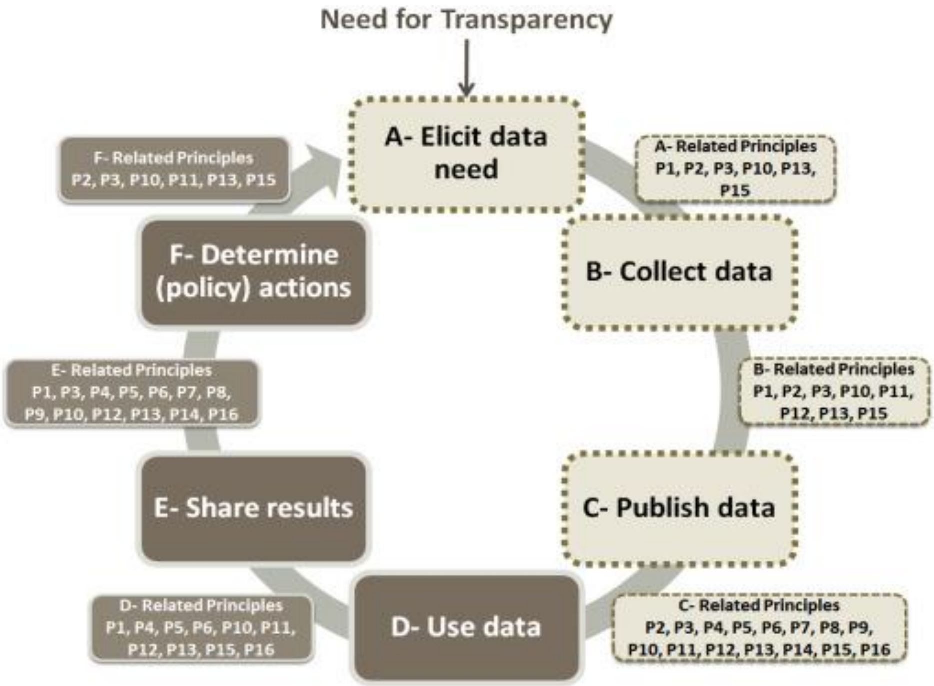

Figure 2: Data-Driven Transparency Cycle from Matheus et al. (2021)

Together, these frameworks offer complementary and evolving perspectives on transparency, marking a conceptual progression from internal system design to adaptive institutional capacity. While Cappelli et al. (2013) provide an outcome-oriented roadmap for evaluating transparency maturity, subsequent models emphasize the socio-technical and organizational conditions necessary for transparency to be effectively realized and sustained.

The BOLD framework by Matheus and Janssen (2015) focuses primarily on the internal decision-making points and technical structures that underpin data disclosure and use. Building on this, the Window Theory (Matheus & Janssen, 2020) introduces a context-sensitive perspective, arguing that transparency outcomes depend not only on disclosure practices but also on factors such as system quality, user literacy, and organizational readiness. The Data-Driven Transparency Cycle (Matheus et al., 2021) advances this line of thinking by connecting connects institutional transparency data practices to the public, making it an outward-facing, iterative process that actively connects institutional data practices with public needs and engagement. In doing so, it aligns with the logic of dynamic capabilities (Teece, 2016), by emphasizing the need for organizations to sense emerging transparency needs, seize opportunities for participation and actions, and transform institutional practices and routines in response to changing environments.

This dynamic framing is particularly well suited to people-centered smart cities, where transparency must evolve in tandem with shifting civic expectations, institutional reforms, and technological developments. Across these frameworks, a critical insight emerges: transparency requires intentional design, robust feedback mechanisms, and continuous alignment across technological, organizational, and societal dimensions.

These foundational perspectives collectively inform the development of the IoT Transparency Maturity Model (IoT-TMM) in this study. The model synthesizes the conceptual transparency qualities articulated by Cappelli et al. (2013) with the iterative, user-centered approaches advanced by Matheus and Janssen (2015) and Matheus et al. (2021). It extends this understanding by framing transparency as a dynamic, learning-oriented capability, enabling municipalities to adapt to the evolving demands of smart city environments.

2.3 Contours of Transparency: Towards a People-Centered Approach

Recent scholarship increasingly call for re-centering transparency around people rather than institutions or systems. A people-centered approach recognizes that transparency must go beyond fulfilling bureaucratic or legal mandates to meaningfully support the informational needs, rights, and agency of citizens (Ahmad et al., 2020; David et al., 2015; Matheus & Janssen, 2020; Vakarelov & Rogerson, 2020). This perspective shifts the emphasis from the supply side of transparency—what governments disclose—by equally prioritizing the demand side: how citizens access, interpret, and act upon information (Fox, 2007). In this view, transparency is not a unidirectional administrative output, but a participatory, iterative process that involves continuous engagement between civic publics and institutional actors.

To realize this vision, *first*, participatory mechanisms must be embedded into the design and implementation of transparency practices. Merely broadcasting information without channels for feedback, contestation, or co-creation risks perpetuating passive citizenship (Bastardo & Rocha, 2024; Bastos et al., 2022; Cardullo & Kitchin, 2017; Falco & Kleinhans, 2018; Simonofski et al., 2021). Practices like participatory audits, living labs, co-designed data governance frameworks, and transparency-by-design portals (Lnenicka & Nikiforova, 2021) exemplify this shift, enabling transparency to become a two-way interaction toward mutual learning and collaborative oversight rather than a one-way dissemination.

Second, to further refine our understanding of information disclosure, Fox (2007) introduces a crucial distinction between two mechanisms of information disclosure: proactive and demand-driven transparency. Proactive transparency refers to information governments choose to make public without prior requests, such as environmental reports or policy evaluations (Fox, 2007). Demand-driven transparency, on the other hand, arises when institutions respond to citizen or media inquiries, through mechanisms such as Freedom of Information requests or ombudsman offices (Fox, 2007). While both are vital, proactive dissemination risks being a formalistic exercise if not curated to meet citizens' needs for actionability and understanding. While both forms are essential, the effectiveness of proactive transparency hinges on its ability to meet citizens' needs for actionable and understandable information (Fox, 2007).

This relationship between information availability and citizen needs is particularly relevant in the context of smart cities, where transparency is often positioned as a pathway to public participation. Empirical studies highlights that meaningful citizen involvement reduces project failures and enhances the legitimacy of smart city initiatives (Shaffer, 2023); However, Bastos et al., (2022) cautioned against a persistent gap; public participation efforts, often, still fall short and remain limited to passive data collection or feedback mechanisms, rather than empowering citizens with substantive roles in governance. Addressing this gap is critical for ensuring the long-term success and inclusivity of smart city projects.

Third, trust-building must be positioned as a central outcome of transparency efforts; transparency cannot be an end in itself; it must contribute to building sustainable trust relationships between citizens and institutions (Pink et al., 2018). Trust hinges not only on the availability of information but on perceptions of fairness, inclusivity, responsiveness, and accountability, as well as the medium used for transparency (Grimmelikhuijsen, 2012; Porumbescu, 2017). Consequently, transparency initiatives should be designed to demonstrate institutional responsiveness to citizen feedback, support oversight mechanisms, and embed transparency into broader systems of democratic deliberation (Matheus & Janssen, 2020).

Fourth, technological mediation must be approached with critical sensitivity. In smart city contexts, transparency increasingly depends on digital infrastructures such as open data platforms, sensor registries, and IoT explainability tools (Bertot et al., 2010; Matheus & Janssen, 2020; Matheus & Janssen, 2015; Porumbescu, 2017). While these technologies can enhance access, they can also introduce new forms of technological opacity or reinforce existing digital divides if not carefully designed (Kitchin, 2016).

Together, these four interrelated dimensions—demand-responsiveness, participatory engagement, trust-building, and technological mediation—emerge from both the literature and empirical insights from interviews with city officials, civic designers, and urban technology providers. They provide the foundation for rethinking transparency as a dynamic capability (Teece, 2016). Importantly, these dimensions also underpin and reframe the operationalization of the below five core transparency qualities, originally proposed by Cappelli et al. (2013), through a people-centered lens: accessibility, usability, informativeness, understandability, and auditability.

Accessibility

The term *accessibility* is frequently invoked in discussions of transparency, yet it also remains conceptually ambiguous in academic literature. This ambiguity necessitates a careful differentiation between accessibility and related concepts such as openness (see section 2.1), usability, and sufficiency. Cappelli et al. (2013) define accessibility as the presence of features like portability, availability, and publicity—features that help ensure data is technically and legally reachable. However, this definition largely ignores user context and primarily addresses structural openness without consideration to specific user needs.

On the other hand, Sheoran et al. (2023), Matheus and Janssen (2015), and Lnenicka and Nikiforova (2021), reinforce the view that accessibility should not be limited to availability or openness, while necessary precondition, but must also consider conditions that enable meaningful access such as usability, clarity, and/or understandability. For example, poorly designed government portals—while nominally "open"—can dissuade usage through complexity and poor interface design, such as difficult navigation or low readability (Sheoran et al., 2023). However, scholars such as Baldo et al. (2023) stress that accessibility is distinct from usability. In that, usability caters to a general audience, whereas accessibility specifically addresses the needs of individuals with disabilities. This distinction is vital to prevent the dilution of accessibility concerns within broader usability discussions. Vakarelov and Rogerson (2020), however, add a deeper layer, distinguishing between accessibility and *sufficiency*: where the former is about making information available and reachable , the latter pertains to whether the information meets public needs, which aligns with Heald (2006)'s outward transparency ensures that public institutions can sense and respond to the needs, and concerns of citizens—completing the feedback loop required for participatory governance and public trust (David et al., 2015; Heald, 2006a).

In the present study, the term *accessibility* is defined narrowly as the extent to which information is made publicly available to everyone —including individuals with disabilities— without technical or procedural barriers. It also includes considerations of sufficiency: whether the information offered aligns with public needs. The usability and clarity aspects of information are treated separately under other dimensions.

Usability

If accessibility determines whether information is available, usability determines whether it can be easily reached without undue effort (Cappelli et al., 2013). Literature consistently demonstrates that usability is a critical enabler for transparency and public engagement. For instance, Cappelli et al. (2013) warn that transparency often fails when interfaces are counterintuitive or difficult to navigate. Lnenicka and Nikiforova (2021) and Rodríguez Bolívar (2018) extend this by foregrounding user-centered design—interfaces built with diverse user journeys in mind. Sheoran et al. (2023) further highlight that usability directly enhances public trust, especially when citizens can easily locate and personalize the data they seek.

To assess usability more systematically, Murmann and Fischer-Hübner (2017) offer a structured approach to evaluating usability through performance measurement, heuristic testing, and user interviews. These methods reveal obstacles to comprehension that might not appear in technical specifications. Sheoran et al. (2023) further enrich this methodological lens by advocating a blend of non-automated (e.g., heuristic evaluations and user observation) and automated (e.g., task completion metrics, clickstream analysis) usability testing to comprehensively assess transparency platforms. Their approach identifies both surface-level issues and deeper interactional patterns that can undermine user engagement.

Complementing these insights, Matheus et al. (2023) provide practical design recommendations. They emphasize the need to balance efficiency and comprehensiveness in transparency tools. They advocate for systems that support both pre-defined applications for less technical users and raw data for advanced analysts—highlighting how flexibility in design enhances both usability and perceived usefulness. Their findings reinforce the importance of user-centered design as a strategy not only for improving usability, but also for deepening trust and engagement in transparency initiatives.

Thus, usability, in this study, refers to the degree with which users can efficiently and effectively navigate and interact with a platform or dataset to achieve their goals, focusing on interface design, personalization, and efficiency.

Informativeness

Where accessibility is about availability and usability about interface design, informativeness pertains to the quality and meaningfulness of the content itself. That is, once users are able to access and navigate information, the next question becomes: is the content meaningful and actionable?

Lnenicka and Nikiforova (2021) criticize practices such as "data dumping"—the release of raw datasets without accompanying context, documentation, or metadata—arguing that such approaches fail to support meaningful use. Similarly, Albu and Flyverbom (2019) warn of "data asphyxia," where an overwhelming volume of information confuses rather than enlightens. In response, scholars like Matheus et al. (2021) and Suzor et al. (2019) advocate for the use of interpretive tools such as layered and structured explanations, filtering mechanisms, and visual tools to help users navigate and interpret complex data environments.

Barcellos et al. (2022) further emphasize that informativeness hinges on attributes of data quality such as accuracy, consistency, and contextual framing. A dataset may be technically complete, but without appropriate interpretive tools, it risks being incomprehensible to its intended audience. Therefore, people-centered transparency depends on translating technical, bureaucratic, or legalistic language into accessible formats that accommodate diverse literacy levels, digital skills, and socio-cultural contexts (Pernagallo & Torrisi, 2020). This includes the use of visualizations, filters, and analytical tools that enable citizens to explore data from multiple perspectives, thereby enhancing perceived transparency (Bastos et al., 2022; Matheus et al., 2021; Suzor et al., 2019).

Efforts such as plain-language communication, interactive dashboards, visual explainers, and citizen-oriented metadata design illustrate practical steps toward this goal (Lnenicka et al., 2022). Moreover, metadata, semantic structures, and standardized vocabularies play a critical role in conveying the meaning and relevance of data (Barcellos et al., 2022).

Thus, Interpretability-enhancing tools—such as readable documentation, standardized metadata, and interactive features—are essential for turning raw data into actionable knowledge. Drawing on Human-Data Interaction (HDI) principles, Barcellos et al. (2022) reinforce that user agency and readability are not optional add-ons but fundamental elements of truly understandable and effective transparency systems.

In this study**,** informativeness refers to the clarity, completeness of the data, ensuring that users receive data that is structured and meaningful enough to support understanding (Barcellos et al., 2022).

Understandability

Closely linked to informativeness, understandability shifts the focus from data quality to data literacy. While Informativeness centers around content-clarity, understandability centers on the user's cognitive ability to comprehend and make sense of data, draw inferences, and act on those insights (Albu & Flyverbom, 2019; Weil et al., 2013). This cognitive and educational capacity is shaped by individuals' data literacy level, their evolving mental models, and the presence of infrastructures that promote reflection and public learning.

Data literacy —an increasingly vital skill in today's data-driven society—refers to the cognitive ability to understand, interpret, and use data effectively (Frank et al., 2016). As data becomes increasingly embedded in everyday contexts, a phenomenon called datafication, this ability has become essential (Frank et al., 2016). However, despite the ambitious goals to promote transparency, social innovation, sustainable development, and political engagement, it has largely fallen short of expectations. Frank et al. (2016) attribute this shortfall to the persistent gap between the availability of data and the public's capacity to engage with it meaningfully. The ideal of the "armchair auditor"—a well-informed citizen independently analyzing open data to hold institutions accountable—has rarely been realized in practice (Frank et al., 2016). Instead, most individuals continue to rely on intermediaries such as journalists, to interpret and contextualize data on their behalf (Frank et al., 2016). This disconnect has brought renewed attention to data literacy as a critical enabler of transparency. As Frank et al. (2016) emphasize, individuals must possess the skills to extract meaning from it in order to make it actionable.

Building on this, Wolff et al. (2016) introduced an inquiry-based approach to data literacy, arguing that it involves the ability to formulate questions, collect and analyze data, critique findings, and communicate insights through visual or narrative means. They emphasize that data literacy is best developed through iterative, contextual learning processes, which help individuals connect abstract data to tangible, lived experiences. Importantly, Wolff et al. stress that different roles—such as readers, communicators, makers, and data scientists—require different depths and types of data literacy.

Complementing this view, mental models play a crucial role in shaping how people understand and respond to data. As Jimerson (2014) explains, mental models are internal frameworks composed of assumptions, definitions, and beliefs that shape how people perceive, interpret, and act upon information (Jimerson, 2014). These models influence how users engage with data, determine what they consider valid or useful, and affect their responses to disclosed information. Importantly, mental models are not static. They evolve in response to new experiences, education, social interactions, and leadership cues. They may be reinforced through routine and organizational norms or reshaped when individuals are exposed to alternative perspectives and reflective learning environments, even in structured environments like schools, many users struggle to form coherent mental models without intentional support (Jimerson, 2014). Further reinforcing this point, Weil et al. (2013) highlight that individuals often rely on cognitive shortcuts—heuristics that help navigate complexity but can also lead to misjudgments. For example, people may overestimate unfamiliar risks, or underestimate risks they feel they can control.

Sander (2024) expands on the discussion of mental models by introducing the concept of *critical datafication literacy*, which challenges the traditional focus on teaching the functional specifics of individual platforms or technologies. Sander (2024) argues that such platform-specific knowledge quickly becomes obsolete in the face of rapidly evolving, often opaque ("black box") data systems. Instead, she advocates for cultivating what she terms "tech intuition"—a form of ethical and critical thinking that equips individuals to engage thoughtfully with new technologies, even when their inner workings are not fully transparent or comprehensible. This shift emphasizes the importance of fostering the ability to make informed judgments about the social impacts of data systems, rather than merely understanding their technical details. Sander contends that public literacy campaigns, participatory workshops, and interpretive tools are essential to bridge the gap between visibility and comprehension. Her framework seeks to equip citizens not only with functional awareness of data practices but also with the critical capacity to interpret, contextualize, and act upon data-driven systems in ways that are reflective, inclusive, and ethically grounded.

Taken together, These insights converge on a shared premise: *understandability* is not an automatic outcome of data release—it must be cultivated (Albu & Flyverbom, 2019). As a socially embedded and developmental capacity, understandability depends on the formation of mental models (Jimerson, 2014), the development of tech-intuition and critical literacy (Sander, 2024), and inquiry-based learning approaches (Wolff et al., 2016). All point to the necessity of embedding educational infrastructures within transparency initiatives.

Auditability

The final but cornerstone dimension is auditability, defined as the ability to trace, verify, and challenge disclosed information (Cappelli et al., 2013), which transforms transparency from passive access to active verification. Suzor et al. (2019) Suzor et al. (2019) build on this by introducing the concept of "communicative accountability"—the idea that institutions must open themselves to scrutiny, feedback, and contestation. Jakonen (2023) further expands the notion of auditability by emphasizing that auditability should also empower citizens to co-produce data, integrate local knowledge, and even audit their own environments.

Additionally, the integration of technology offers promising avenues for enhancing oversight and verification, such as feedback loops, enabling stakeholders to scrutinize and challenge official data is deemed essential in people-centered transparency systems (Lnenicka & Nikiforova, 2021; Williams, 2015). Technologies like blockchain, for instance, can create immutable records and transparent audit trails, enabling both technical and participatory verification of data (Chanson et al., 2019; Bastardo & Rocha, 2024). These systems help reduce the risk of manipulation while fostering public trust. Furthermore, incentive mechanisms, such as gamification or monetary rewards can further motivate citizen engagement in these crucial verification processes, fostering trust between institutions and the public (Bastardo & Rocha, 2024).

In this study, auditability is defined as the capacity to verify the accuracy, relevance, and trustworthiness of disclosed information through both institutional mechanisms and public scrutiny. This dimension ensures that transparency extends toward accountability, anchoring trust in the verification of information.

To better articulate the distinct yet interrelated qualities of effective information transparency in smart cities, Table 1 summarizes the five key qualities: Accessibility, Usability, Informativeness, Understandability, and Auditability

Dimension	Definition	Mechanism	Dependencies
Accessibility	Extent to which information is publicly available and aligned with public needs.	Functionality-based apps and websites, Open data portals, APIs, accessibility standards.	Foundation for all other dimensions.
Usability	The ease with which users can navigate and interact with the interface.	Responsive and user-friendly dashboards, interface, customization, search filters, map-based.	Requires accessibility and enhances informativeness and understandability.
Informativeness	Clarity, completeness, and contextual relevance of data, ensuring meaningful and actionable content.	Contextual metadata, labelling, categorization, semantic precision.	Depends on accessibility and usability; prerequisite for understandability.
Understandability	Degree to which the public is cognitively prepared, and the information meets diverse literacy and interpretive capacities.	Clear language, visualization, translation, literacy campaigns and support	Dependent on informativeness and usability
Auditability	The ability to verify the accuracy and trustworthiness of the information published.	Feedback mechanisms, traceability logs, blockchain, citizen verification, oversight agents	Closes the loop by enabling scrutiny of all previous dimensions.

Table 1: A Summary of Transparency Dimensions and Dependencies

Ultimately, well-designed transparency mechanisms that prioritize public involvement and incorporate feedback channels are crucial for building trust in institutions, improving policy effectiveness, and establishing a robust system for ongoing public oversight (David et al., 2015). When transparency is interactive, empowering, and rooted in citizen co-production, it evolves into a dynamic tool for auditability and democratic governance. The introduction of an independent oversight agent—whether an institution, watchdog organization, or dedicated public body—is also central to ensuring auditability by verifying not only the disclosure of information but also its comprehensibility and usability, thereby transforming raw data into actionable knowledge for effective public scrutiny (Vakarelov & Rogerson, 2020). Engaging citizens directly in decision-making processes through public consultations and collaborative governance initiatives, as highlighted by Cucciniello et al. (2016), further enhances auditability by allowing the public to influence policy outcomes and hold officials accountable. In this context, transparency enhancing tools can play a vital role in operationalizing a people-centred approach.

2.4 Transparency-Enhancing Tools: Challenges and Opportunities

To fulfil the informational requirements discussed in Section 2.3, the concept of Transparency-Enhancing Technologies (TETs) has emerged. TETs are technological mechanisms that provide users with clear, accessible, and accurate insights into how their personal data is being collected, stored, processed, and shared (Janic et al., 2013).

Unlike Privacy-Enhancing Technologies (PETs)—which aim to prevent or minimize data collection and processing through technical safeguards—TETs do not directly prevent the collection or misuse of data. Instead, they enhance "user awareness" by making data practices visible and comprehensible. As both tools support privacy, either directly or indirectly, some scholars use the two terms interchangeably, however, in this paper, we make a clear distinction between PETs as proactive and preventative tools that allow the user to limit or obfuscate data collection through Graphical User Interface (GUI), and TETs that are passive and explanatory tools that reveal and clarify how data is being handled (Janic et al., 2013).

This distinction is especially important in the context of smart cities, where passive data collection—through sensors, IoT devices, and ambient systems—is pervasive and often invisible to citizens; In such cases, TETs are particularly suitable, as they can make hidden data flows transparent. Accordingly, this paper adopts a focused definition of TETs as tools designed to increase visibility of "silent data" collection in environments typical of smart cities (Ahmad et al., 2020; Jameson et al., 2019; Janic et al., 2013; Keenan, 2009; Long et al., 2024; Urquhart et al., 2019).

Many TETs have been developed for web-based and platform-centric environments, such as e-commerce websites, social networks, and mobile apps, where users typically create identifiable accounts, provide explicit consent, and interact through visual interfaces. Janic et al. (2013) offer a comprehensive review of early TETs designed to increase trust by clarifying how online services collect, store, share, and use personal data. Their typology identifies tools like Mozilla Privacy Icons, Google Dashboard, and Web of Trust, which translate privacy policies into more accessible visual formats, offer dashboards for data visibility, or rate websites based on community trust and transparency scores. Zimmermann (2015) further classified TETs according to features like interactivity (read/write), assurance level (trusted/semi-trusted), application time (ex-ante/ex-post), and execution environment (client/server). While comprehensive, these classifications presume a browser-based interaction, where users are also presumed to engage with digital platforms voluntarily and can exercise control by choosing whether to accept data practices.

However, these assumptions does not hold entirely in the context of Internet of Things (IoT) systems, where data is typically collected passively without direct user interaction (Ahmad et al., 2020; Long et al., 2024). To bridge this gap, Long et al. (2024) identified TETs that can enhance transparency for Internet of Things (IoT) environments. Among these tools are privacy labels, inspired by nutritional labeling, which succinctly communicate the privacy risks associated with specific devices, to build mental models. Contextual notifications provide real-time alerts when the user connects to a network with IoT devices connected to, offering situational awareness about ongoing data collection. In parallel, advances in Natural Language Processing (NLP), "a branch of Artificial Intelligence that helps computers understand, interpret, and manipulate human language" and used today in functions such as chatbots and smartphone voice assistants (Zohuri et al., 2022), have facilitated the development of simplified privacy policies, enhancing their clarity and reducing interpretive burden, as well as a unified transparency platforms aggregate data-related information across multiple devices into a single interface, promoting holistic oversight.

While these tools offer promising advances in making privacy more transparent for IoT devices, they were still aimed at private, individually owned devices—such as smart thermostats or wearable tech. In public urban environments, however, users have no direct interaction with most data-collecting devices, therefore, there is no moment of "connection" at which a contextual notification could be triggered, nor any platform for users to centrally manage city-owned sensor data streams. Therefore, in the context of urban environments, many conventional TETs are poorly adapted.

Thus, recent approaches have sought to reimagine TETs as place-based, spatially embedded instruments that can inform and empower individuals in physical public spaces. Unlike the previous technical driven tools, people-driven frameworks such as the Digital Trust for Places and Routines (DTPR) have emerged. DTPR tools, as illustrated in Figure 3 and 4, use physical signage, QR codes, and standardized metadata to disclose data practices in physical public space (Farra & Lu, 2023; Shaffer, 2023).

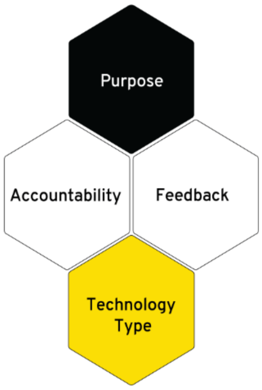

Figure 3: Design Guideline for the DTPR (Farra & Lu, 2023)

Figure 4: Example of the Signs Installed (Farra & Lu, 2023)

DTPR provides a standardized system for visually communicating data collection and governance in public places. It uses signage with intuitive icons, QR codes linking to detailed data explanations, and taxonomies that describe data types, purposes, and retention policies. DTPR has been piloted in cities such as Washington, DC; Long Beach, California; Sydney, Australia; Boston; and Angers Loire, France, with promising results.

In Washington, DC's Pedestrian and Cyclist Safety Sandbox Project, signage incorporating icons and QR codes linked to a "Guide App" provided contextual information about deployed technologies. Residents could view who was operating the sensors, what data was being collected, and why. This increased transparency led to higher levels of engagement and public feedback (Farra & Lu, 2023). Similarly, in Long Beach, DTPR signage was deployed next to technologies like automated license plate readers and eco-totems. The signs, available in multiple languages, described data collection practices and linked to a digital rights platform that enabled deeper interaction. Public workshops and “data walks” allowed residents to co-develop policies and raise concerns about surveillance and retention (Shaffer, 2023). These examples demonstrate how DTPR tools act as awareness and policy communication TETs, helping residents build mental models of data governance—much like how standardized traffic signals provide intuitive understanding of mobility rules.

Importantly, these interventions also contributed to internal accountability. In Sydney, for instance, DTPR signage and metadata templates helped city officials standardize vendor reporting and verify compliance with data protection regulations. In Washington, the structured taxonomy used to collect metadata from vendors facilitated interdepartmental coordination and compliance auditing, thus functioning as an auditability tool that supports organizational governance as much as public transparency.

Collectively, these initiatives and experiences highlight several key opportunities and challenges. First, transparency must be actionable and comprehensible—information alone is insufficient if not accessible, usable, and presented in ways that citizens can intuitively understand (Matheus & Janssen, 2020; Pink et al., 2018). Second, the standardization of data disclosure practices—whether via DTPR signage, sensor registries, or open metadata schemas—not only supports public awareness but also improves internal data governance and accountability (Expert Interview, 2025). Third, genuine participation is essential; co-design workshops, citizen feedback loops, and public engagement events transform residents from passive data subjects into active stakeholders in smart city governance (Shaffer, 2023).

However, challenges remain in institutionalizing and scaling these efforts beyond pilot phases. Participants noted the absence of formal ownership and integration into core governance processes. Moreover, many tools still lack dynamic content, multilingual accessibility, or mechanisms for real-time updates—limiting their effectiveness over time. For DTPR and related TETs to fulfill their potential, they must be embedded within broader governance frameworks that support iteration, adaptation, and scalability.

These theoretical foundations inform the design of the IoT-TMM proposed in this study, which aims to guide municipalities to assess, evolve, and institutionalize transparency practices to be both inclusive and adaptive to changing civic expectations. The IoT-TMM model builds on key principles from Cappelli et al. (2013), Matheus and Janssen (2015), Matheus et al. (2021), providing an iterative, self-assessment-based framework that enables municipalities to diagnose current practices and incrementally strengthen their transparency capabilities over time (Becker et al., 2009; Cappelli et al., 2013). Importantly, the model extends the concept of Transparency-Enhancing Technologies (TETs) beyond traditional graphical interfaces and privacy tools, positioning transparency as a city-scale governance infrastructure embedded within institutional processes and public service design.

3 Methodology

This study employs Design Science Research Methodology (DSRM) as outlined by Hevner and Ram (2004) to develop an IoT Transparency Maturity Model (IoT-TMM) tailored for public IoT systems in smart cities. DSRM emphasizes the iterative design, development, and validation of artifacts that address real-world problems through rigorous academic inquiry and stakeholder engagement (Hevner & Ram, 2004). The model was developed by integrating design approaches from Aljowder et al. (2023) and Becker et al. (2009), which ensures that the model is grounded in validated processes and benefits from the cumulative experience of prior maturity model designs, with necessary contextual adaptations (Aljowder et al., 2023; Becker et al., 2009). The artifact—the IoT-TMM—aims to serve as a diagnostic and strategic tool for assessing and improving transparency practices among public authorities, municipalities, technology vendors, smart cities architects, and other stakeholders, focusing on issues such as the transparency of IoT privacy policies in smart cities.

DSR is particularly valuable in bridging the persistent gap between academic theory and practical implementation (Johannesson & Perjons, 2021). DSR aims to produce satisfactory artifacts that can be adapted, tested, and improved upon in different contexts. Accordingly, the IoT-TMM provides actionable guidance for real-world challenges, while remaining open to future iterations and expansions.

To structure the research process, the Design Science Research (DSR) framework proposed by Johannesson and Perjons (2021) was employed as a methodological guide. This framework outlines five core activities that shape the progression of a DSR project: explicating the problem, defining requirements, designing and developing the artifact, demonstrating its application, and evaluating its effectiveness. These stages are illustrated in Figure 5.

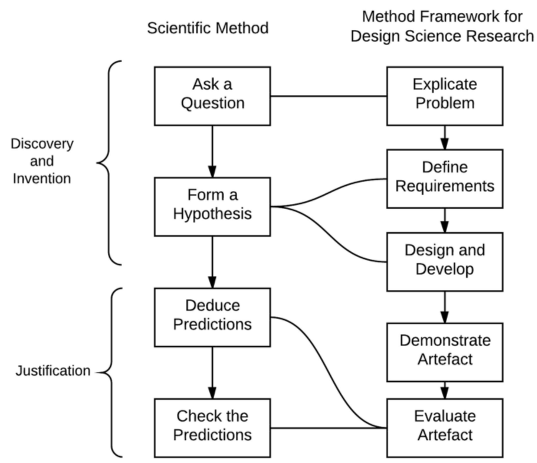

Figure 5: DSR Framework

3.1 Problem Identification

To define the problem space, a two-phase investigation was conducted, combining a comprehensive literature review and expert interviews. To the best of our knowledge, the literature highlighted the absence of dedicated maturity models targeting IoT transparency for smart cities, while interviews revealed recurring practical challenges, including the scalability of transparency initiatives, lack of accountability mechanisms, unclear data ownership, and insufficient citizen engagement. The empirical component of this study draws on expert interviews and case-based observation. These methods were selected to elicit nuanced perspectives on transparency in smart city IoT deployments and to gather practitioners' feedback on the IoT-TMM prototype.

Literature Review

Literature review was conducted using Web of Science, Limo, and Google Scholar, focusing on transparency, accountability, privacy, and transparency-enhancing technologies (TETs) in smart cities. Search strings included combinations such as ("sensor" OR "IoT" OR "AIoT") AND ("transparency" OR "privacy" OR "accountability") AND ("smart city" OR "maturity model"). Only English-language sources were included. Forward and backward citation tracking ensured comprehensiveness (Gusenbauer & Gauster, 2025). Previous maturity models were critically analyzed for scope, structure, and real-world applicability, informing the development of more targeted and actionable transparency practices and dimensions.

Expert Interviews

To support the development of the IoT-TMM, eleven expert interviews were conducted. The selection of participants was purposive, targeting individuals with direct involvement in municipal IoT deployments, transparency initiatives, and smart city governance (Rai & Thapa, 2015). Fugard and Potts (2015) argue that the appropriate number of interviewees in design-oriented research should strike a balance between capturing sufficient diversity and avoiding unmanageable complexity. Empirical evidence suggests that theoretical saturation is frequently reached after approximately six interviews (Fugard et al., 2015). Based on this guidance, the eleven interviews conducted for this study were deemed sufficient to generate meaningful insights while ensuring analytical feasibility. To further enrich the range of perspectives, a snowball sampling approach was utilized, allowing participants to suggest additional relevant stakeholders.

The experts represented diverse roles, the roles and affiliations of the interviewees are summarized in Table 2. To preserve anonymity and confidentiality, identifying details have been omitted or generalized. The selection aimed to ensure diverse stakeholder perspectives relevant to transparency in smart city contexts. Most interviewees were based in the Netherlands, reflecting its active smart city experimentation (Jameson et al., 2019). However, Additional insights were gathered from experts based in New York City and Canada. This international lens strengthens the external validity and transferability of the model by grounding it in varying institutional, regulatory, and cultural contexts. It also enhances the potential for broader relevance.

Interviewees were consulted at different phases of the research. Some were involved during both the initial problem definition and evaluation stages to provide feedback on the artifact, while others were engaged during either problem definition or model design stages. This iterative consultation process aligns with the principles of Design Science Research (Hevner et al., 2004), which emphasize ongoing stakeholder engagement for artifact refinement, assessing the usability, structure, and potential adoption of the IoT-TMM prior to its finalization. This feedback loop supported iterative refinement of the model and helped align it with real-world implementation needs.

The full set of semi-structured interview questions is presented in Table 3, structured to elicit insights across the problem definition, design, and evaluation stages of the IoT-

TMM. Findings were triangulated with literature to refine model requirements and inform the design process. This ensured that the model was not only theoretically grounded but also practically aligned with real-world constraints and opportunities across different municipal and technological contexts.

No.	Role	Organization	Country	Frequency	Interview Period
1	IT admin	Municipality	The Netherlands	Two time	Problem definition/design and development, and evaluation
2	Transparency tools Project Manager	Municipality	The Netherlands	One time	Problem definition/design and development
3	Innovation Manager 1	Municipality	The Netherlands	Two time	Problem definition/design and development, and evaluation.
4	Smart City Architect & Transparency dvocate	Smart City Center	The Netherlands	Two times	Problem definition/design and development and evaluation
5	Social designer	Social Design Organization	The Netherlands	One time	Problem definition/design and development
6	Digital Trust expert 1	Social Design Organization	Canada	One time	Problem definition/design and development
7	Digital Trust expert 2	Social Design Organization	Canada	One time	Problem definition/design and development
8	Innovation Manager 2	Municipality	The USA	One time	Problem definition
9	IT admin	Municipality	The USA	One time	Problem definition
10	Maturity model developer	Consultancy	International	One Time	Design and development
11	Sensor's registry consultant	Software company	The Netherlands	One Time	Design and development

Table 2: Experts Consulted

No.	Goals	Key questions posed
1	To acquire an overview of the current transparency efforts in general and the IoT sensors in particular.	-What methods or technologies have you used to communicate the presence and purpose of IoT sensors to the public, and how effective have these approaches been? -What communication challenges have you encountered when explaining sensor-based data collection to citizens? -Could you describe the process of creating and maintaining a public sensor registry in your city? What challenges have emerged? -How do you map physical sensor deployments to publicly accessible transparency platforms (e.g., maps, dashboards)? -What do you tailor information ensure it is comprehensible, and relevant to diverse audiences in public space? -How small municipalities, compared to large municipalities, manage the required resources for transparency?
2	To get a better understanding of stakeholders and users involved	Who are the key stakeholders and organizations you work with in the transparency process and what are their roles? How are the public involved in this process?
3	To get a better understanding of challenges faced by officials and the public	What challenges have emerged during elicitation, publishing privacy information?
4	To get a better understanding of multi phases of operationalization of transparency	What steps are essential for elicitation, publishing, and use of privacy information?
5	To receive feedback and discuss aspects to improve artefacts during evaluation stage	How practical and relevant do you find the maturity model (for your organization)?

Table 3: Interview Questions

3.2 Requirements Definition

The requirements for the transparency maturity model were identified and curated through an extensive literature review and expert interviews, as outlined in section 3.1, and demonstrated in Chapter 2.

3.3 Design and Development

The use of maturity models to guide organizational development is well-established across fields such as information systems and organization development (Becker et al., 2009). These models offer a structured, phased approach for assessing current practices, identifying capability gaps, and planning progressive improvements (Becker et al., 2009). Their staged design supports scalability and incremental growth—from pilot projects to organization-wide transformations (Paulk et al., 1993). They also facilitate institutionalization by embedding responsibilities, standardizing processes, and fostering continuous learning (Plattfaut et al., 2011).

To address the persistent challenges of fragmented application, lack of ownership, and weak institutionalization in the implementation of transparency practices across smart city initiatives, this study adopts a maturity model approach. IoT-TMM offer structured, evolutionary paths for organizations to move from ad hoc, inconsistent disclosure to systematically institutionalized practices. As Safari et al., (2013) note, mature organizations are distinguished not by individual effort, but by disciplined, repeatable processes grounded in strategic and operational alignment.

In the context of transparency, maturity models help shift efforts from ad hoc or symbolic disclosure toward sustained, people-centred, and strategically governed practices (Cappelli et al., 2013). Prior models, discussed in 2.2, have shown to enable public institutions to treat transparency as a dynamic and adaptive capability (Cappelli et al., 2013; Matheus et al., 2021). Building on this foundation, the IoT-Transparency Maturity Model developed in this study is positioned as a tool for operationalizing, institutionalizing, and scaling IoT transparency practices within smart city.

The process was further guided by Aljowder et al. (2023) procedural framework for developing focus area maturity models (Figure 6). The scope of the focus areas and requirements were identified through literature review and expert interviews (as discussed in 3.1 and 3.2). Key practices and capabilities within each dimension were then specified to represent incremental maturity milestones, and their interdependencies were then identified to specify the logical progression and positioned in a matrix structure, reflecting interdependencies and layered development (as illustrated in Table 1). To support implementation, the model includes general improvement actions to help municipalities progress from lower to higher maturity levels.

Development framework for focus area maturity models	Identify the scope and functional domain	Decide on what to include and exclude
	Determine focus areas	Based on the literature review, then exploratory methods
	Determine capabilities	Capabilities define the incremental path for maturity levels' progress
	Determine dependencies	Specify the order of the capabilities within and between focus areas
	Position capabilities in matrix	Based on the specified dependencies
	Develop assessment instrument	Specify assessment questions for the capabilities based on the description
	Define improvement actions	General suggestions
	Implement maturity model	The first implementation is for model evaluation
	Improve matrix iteratively	Enough assessment data to be collected for the model evaluation
	Communicate results	To practitioners and academia

Figure 6: Focus Area Maturity Models Development (Aljowder et al., 2023)

Operationalizing Transparency

To guide the systematic design and implementation of people-centered transparency practices, the study adopts a combined approach of two methods:

First, The Goal-Question-Operationalization (GQO) method. GQO— derived from the well-established Goal–Question–Metric (GQM) framework, supports the translation of transparency qualities into specific practices by defining goals, posing questions, and identifying operational practices (Cappelli et al., 2013; Serrano & Leite, 2011). Within this study, GQO serves as a methodological bridge between normative transparency objectives and context-specific operational practices suitable for smart city's Internet of Things (IoT) environments. A range of methods were employed to support the identification of causal relationships between the high-level goals and the operational practices, as advised by Oliveira et al. (2016), the study employed a multi-method approach, including document analysis, interviews, and academic literature. Initial data collection involved document analysis to understand formal process requirements and interviews with domain experts to explore both documented and undocumented practices. These empirical insights were then contextualized and strengthened by drawing upon academic literature that conceptually links transparency-enabling practices to organizational structures and procedures. Crucially, the engagement of domain experts ensured that the operationalized practices were not only technically feasible but also socially legitimate and contextually appropriate (Cappelli et al., 2013; Serrano & Leite, 2011).

Second, the study employs the McKinsey 7S Framework—originally developed as a change management tool— to guide organizational change by embedding previously defined practices (in step 1) within the internal environment of the organization. The relevance of the McKinsey 7S model lies in two key aspects. First, its effectiveness in driving organizations to achieve desired goals, through alignment of as many as possible of the seven interrelated elements—Strategy, Structure, Systems, Staff, Skills, Style, and Shared Values—is recognized as a critical success factor for achieving organizational effectiveness and sustainable change (Alfadhli et al., 2025; Kocaoğlu & Demir, 2019; Suwanda & Nugroho, 2022). The framework provides a structured approach through which practices are not pursued in isolation but integrated holistically across the organization (Alfadhli et al., 2025; Kocaoğlu & Demir, 2019; Suwanda & Nugroho, 2022). Second, the model is highly adaptable, applicable across diverse organizational contexts, including both public and private sectors (Alfadhli et al., 2025).

Ultimately, GQO provides the practical logic for assessing and advancing progress, while the 7S model ensures that each operational element is institutionally supported. Together, these frameworks support a model that is both strategically coherent and participatorily grounded, capable of guiding cities toward higher levels of transparency maturity in a way that is both rigorous and inclusive.

Maturity Model Design

The IoT-TMM was developed to serve three principal functions. First, in its *descriptive* capacity, the model enables organizations to assess the current state of their transparency practices across six core dimensions, thereby facilitating the identification of strengths and areas requiring improvement (Plattfaut et al., 2011). Second, in a *comparative* role, the model supports benchmarking across municipalities or departments. Its application in diverse contexts—such as Amsterdam, The Hague, and the province of Brabant—demonstrated its potential to foster inter-organizational learning despite contextual differences (Plattfaut et al., 2011). Third, in a *prescriptive* function, the model offers a structured yet flexible roadmap for improvement through clearly defined characteristics associated with five maturity levels. Rather than promoting a rigid, linear progression, the IoT-TMM encourages context-sensitive advancement tailored to specific institutional needs and capacities (Plattfaut et al., 2011).

Recognizing that transparency capabilities may mature unevenly across dimensions, the model is deliberately nonlinear, self-assessable, and iterative. It allows municipalities to tailor dimensions or practices to fit specific resources and strategic goals, addressing known shortcomings in smart city transparency efforts—particularly the lack of scalability, continuity, and institutionalization beyond pilots.

The model incorporates six core dimensions—Accessibility, Usability, Informativeness, Understandability, Auditability, and Learnability—adapted and refined from Cappelli et al. (2013), and features five maturity levels: Opaque, Disclosed, Comprehended, Reliable, and Participative.

3.4 Demonstration

The model was applied to real-world use cases and refined through expert feedback. Key stakeholders—including municipal officials, transparency advocates, and technology providers—evaluated its usability, and their insights directly informed final revisions. The model was shared with all experts who participated in the interviews, fostering further reflection and practical exploration. Notably, two experts expressed interest in sharing the model with their teams and using it as a practical guide to enhance transparency efforts. While this paper primarily focuses on the artifact's design and development, it also serves as the primary channel for communicating findings to both academic and practitioner audiences. As recommended by Hevner et al. (2004), this dual dissemination approach supports the translation of design insights into practice and stimulates future research and policy dialogue.

3.5 Evaluation

A variety of methods can be used to evaluate a design artifact. A useful distinction is between *ex ante* and *ex post* evaluations. *Ex ante* evaluations are conducted before an artifact is fully implemented or used in practice, aiming to assess its relevance, utility, and design quality during development (Johannesson & Perjons, 2021). In this study, an *ex-ante* evaluation was conducted through follow-up e-mails with participants, building on the earlier data collection phase. These e-mails enabled targeted feedback on the draft model and facilitated clarification and elaboration of prior insights. The findings from these evaluations are further discussed in Chapter 5 (Results).

Ex ante evaluations offer the advantage of being relatively fast and resource-efficient, making them particularly suitable when timely input is needed to refine an initial prototype. However, such evaluations also carry the risk of false positives—overestimating an artifact's effectiveness based on expert perception rather than actual use (Johannesson & Perjons, 2021). Therefore, to ensure a comprehensive assessment of the model's applicability and robustness, a multi-method evaluation strategy was employed. This included expert validation and three preliminary case studies. Iterative feedback loops helped refine the model, ensuring alignment with legal frameworks such as the General Data Protection Regulation (GDPR) and transparency guidelines.

During the second validation step, the IoT-TMM model was preliminarily applied to three Dutch municipalities, which served both as a validation exercise and a proof-of-concept for real-world relevance. The results informed iterative refinement of the matrix and served as a basis for evaluating both the diagnostic clarity and practical utility of the model. The three Dutch municipalities were selected for preliminary application and assessment: Amsterdam, The Hague, and the province of Brabant. Amsterdam was selected because it was the first municipality in Europe to initiate a Smart City program and has a longstanding tradition of civic engagement and activism around digital technologies (Jameson et al., 2019). The selection of the other two municipalities was guided by two main considerations. First, participants with practical experience in Amsterdam municipal transparency initiatives suggested specific cities that are actively engaged in sensor deployment and transparency efforts. Their recommendations ensured that the selected cases were relevant and reflective of current developments in IoT Transparency. Second, since transparency can be costly and its implementation depends on the capacity of the government (Alfadhli et al., 2025; Grimmelikhuijsen & Welch, 2012), the municipalities were chosen to represent a variation in sizes and resources.

This deliberate variation enabled a broader examination of the model's applicability across different contexts and maturity levels, providing valuable insights into its strengths, limitations, and areas for refinement. The assessment is based on publicly available information, previous interviews, and the expert validation phase. The aim was to explore the practical applicability of the model and identify differences across varying levels of transparency maturity.

Finally, the results and refined model are communicated to both practitioners and academia, through the submission of this dissertation, contributing to broader conversations on how public sector institutions can operationalize transparency not as a static ideal, but as a capability to be assessed, cultivated, and institutionalized.

4 Design and Development

This paper extends Cappelli et al.'s (2013) model by developing practice-oriented maturity model for people-centered transparency. In doing so, we were inspired and informed by the qualities of transparency offered by Cappelli et al.'s (2013) and the strategic, process-oriented, and user-centric perspectives to data lifecycle of Matheus et al. (2021) and Matheus and Janssen's (2015) BOLD model, as described in detail in section 2.2, to ensure practical relevance and impact of transparency, this operationalization is explicitly need-driven, emphasizing the "eliciting data need" phase and the user-centric considerations of Matheus et al.'s (2021) cycle, reflecting the three stages of Teece's (2016) dynamic capability: Sensing, Seizing, and Transforming.

By focusing on understanding and responding to the specific information needs and contextual factors of stakeholders, this research contributes a novel approach that moves beyond a static maturity assessment towards a continuous and dynamic framework for achieving meaningful and impactful transparency.

4.1 IoT-TMM Levels

Building upon the staged maturity approach of Cappelli et al.’s (2013), the proposed IoT-TMM consists of five progressive levels. These stages—opaque, disclosed, comprehended, reliable, and participative. Each stage represents the progression of transparency practices and is aligned with organizational practices that enhance accessibility and clarity of IoT systems privacy policies.

1. Opaque

At the "Opaque" level, data disclosure within IoT systems is either entirely absent, unstructured, or reactive. The public typically has limited or no access to critical information, such as the location of IoT sensors, the types of data being collected, or the purposes for which this data is utilized. This opacity is characterized by several systemic challenges: the absence of clear ownership over transparency initiatives, the lack of formalized processes or governance mechanisms for disclosing privacy policies, and the absence of privacy risk assessments. These gaps significantly heighten the risk of data misuse, unchecked surveillance, and violations of individual privacy rights, and consequently, public distrust and resistance.

Cardullo and Kitchin (2017) described transparency at this level as minimal to nonexistent, and citizen participation is similarly absent. This aligns with the lower rungs of Arnstein's (1969) ladder of participation, specifically, the stages of Non-Participation and Tokenism. In the non-participation phase, decision-making processes are entirely controlled by authorities, with no input from citizens, who remain uninformed and excluded. In the Tokenism stage, while citizens may be given a platform to express their views, these contributions rarely influence outcomes. Thus, even when engagement is superficially present, it lacks substantive impact, and transparency remains deeply compromised. The overall governance model at this stage is top-down and authoritarian, where public oversight is absent and urban management is shielded from civic scrutiny.

This stage marks the foundational level in the IoT-TMM, where the urgency for introducing transparency mechanisms is most critical.

2. Disclosed

The Disclosed level marks a shift where some information is shared with citizens, but meaningful engagement and understanding remain limited. Although data is publicly available, it is often poorly maintained, unstructured, and lacks clear documentation regarding its purpose, retention policies, and associated privacy risks. Furthermore, the public has no substantive influence over sensors deployment decision-making processes, which aligns to level 0 in Aljowder et al.'s (2023) Public Transparency in Smart City Maturity Matrix. Several challenges underpin this condition, including the absence of a structured data model, unclear data ownership, and only basic feedback mechanisms. Crucially, there are no robust accountability frameworks in place to support civic oversight.

At this level, while some information is made accessible to citizens, opportunities for meaningful participation and deep understanding remain limited. This level corresponds to the "Consumerism," "Informing," and "Consultation" stages of citizen participation (Cardullo & Kitchin, 2017). At the Consumerism stage, citizens access smart city services as users but lack insight into or influence over their design. The Informing stage provides one-way communication about decisions, offering little understanding of the underlying processes. In the Consultation stage, citizens can give feedback, but it rarely leads to meaningful changes, as decision-making power remains with authorities. Therefore, the scope of transparency remains narrow, with only superficial responsiveness to public input.

3. Comprehended

At the Comprehended level of transparency and participation, the public is provided with clear and accessible explanations regarding the IoT privacy policies. This reflects a notable improvement over more opaque practices, as citizens are not only informed but also supported in developing a deeper understanding of the processes that influence their environment. This level paves the road to establishing more participatory decision-making. One of the key challenges at this level is the absence of continuous monitoring mechanisms for transparency initiatives, coupled with underdeveloped feedback loops. As a result, citizen input is neither systematically collected nor meaningfully integrated into decision-making processes.

This level of engagement at this level aligns with the "Placation" rung in the ladder of participation proposed by Cardullo and Kitchin (2017), where citizens may be invited to provide input or suggest ideas, but their influence over outcomes remains far from optimum. Although transparency is enhanced—owing to efforts by authorities to make information comprehensible, the capacity of citizens to shape decisions that directly affect them remains constrained. The decision-making process is more open and intelligible, yet substantive power continues to reside with institutional actors. In this sense, the Comprehended level represents progress toward more inclusive governance but still falls short of achieving genuine co-decision-making.

4. Reliable

At the "Reliable" level, Transparency is systematically assessed using performance metrics, supported by audit mechanisms that ensure compliance with established standards. Citizen feedback is actively integrated into governance processes, reinforcing evidence-based decision-making practices. These decisions are regularly reviewed to maintain accuracy, uphold privacy protections, and ensure adherence to ethical guidelines. Transparency extends beyond isolated pilot projects, contributing to the cultivation of institutional memory and fostering long-term knowledge-sharing mechanisms essential for sustainable governance. However, realizing such a level of transparency necessitates a robust organizational commitment, presenting a significant challenge for many institutions.

As conceptualized by Cardullo and Kitchin (2017), there is a consistent and trustworthy flow of information, enabling citizens to depend on the clarity and accuracy of the data provided. This level corresponds to the "Partnership" and "Delegated Power" stages in Arnstein's (1969) ladder of citizen participation. In the Partnership stage, citizens move from passive recipients to active co-creators, sharing decision-making power with authorities. Transparency is ensured through open, accurate, and scrutinizable information. In the Delegated Power stage, citizens hold substantial influence, with transparency becoming deeply participatory. Their input shapes outcomes, reflecting a more equitable power dynamic and heightened civic trust (Cardullo & Kitchin, 2017).

5. Participatory

Transparency at this level is co-created with the public through participatory audits and public monitoring mechanisms, facilitating direct involvement in the governance of IoT systems and the safeguarding of privacy. At the participative level, transparency reaches its fullest expression, with citizens gaining access to all relevant information and actively participating at every stage of decision-making. This level reflects the "Citizen Control" rung of Arnstein's ladder, wherein citizens possess full managerial authority and are directly accountable for decisions that affect their communities (Cardullo & Kitchin, 2017). Here, transparency becomes not only participatory but also reciprocal, citizens both provide and receive information, directly shaping outcomes. In such a configuration, governance shifts from a model dominated by public authorities to one where citizens are the primary decision-makers. This advanced stage of transparency is marked by mutual trust enabling meaningful and impactful civic engagement.

This phase completes Matheus et al.'s (2021) transparency data cycle, by using data, sharing results, and determining actions. It also reach the both scalability types "expansion" and "replication" defined by van Winden and van den Buuse (2017), discussed in 4.2. This level of participatory transparency builds upon a growing body of scholarship that critiques the technocentric orientation of early smart city initiatives. These earlier models often prioritized technological efficiency at the expense of democratic inclusion. In contrast, contemporary research advocates for participatory governance models that prioritize human needs and democratic values (Calzada et al., 2023; Di Bernardo et al., 2023; Jakonen, 2023; Mupfumira et al., 2024; Simonofski et al., 2019).

Table 4 summarizes the key characteristics of the five maturity levels.

Maturity Level	A Summary
Opaque	No defined processes or responsibilities for IoT transparency.
Disclosed	Basic transparency processes exist but are inconsistent.
Comprehended	A structured transparency is implemented, defining responsibilities and disclosure processes.
Reliable	Transparency is systematically measured through performance metrics, with audit mechanisms ensuring compliance.
Participatory	Decision-making processes are shaped by residents actively co-governing sensors deployment and data governance.

Table 4: A Summary of IoT-TMM Levels (Cappelli et al., 2013)

4.2 IoT-TMM Dimensions

As previously stated, this study focuses specifically on transparency of IoT privacy policies in smart cities, concerning data collection, use, and reuse policies governing sensor deployments in smart cities. The objective is to investigate how these policies are made accessible, understandable, and accountable to the public, with particular attention to the mechanisms that enhance citizen awareness and oversight in IoT governance.

The design of the IoT-TMM proposed in this study builds upon the conceptual frameworks established by Cappelli et al. (2013), Matheus et al. (2021) and Matheus and Janssen (2015), integrating both transparency qualities and design principles that address key implementation challenges. Cappelli et al. (2013) conceptualize transparency as a network of five interrelated qualities—accessibility, usability, informativeness, understandability, and auditability—which organizations can satisfice to varying degrees through the deployment of appropriate processes. Matheus et al. (2021) and Matheus and Janssen (2015) extend this understanding by introducing design principles focused on transparency data cycle and feedback mechanisms, thereby providing practical guidance for operationalizing transparency.

Additionally, to reflect the evolving nature of transparency efforts in urban contexts, this model introduces the integration of the dimension *Learnability* as a critical dimension for scalability, to refer to the establishment of organizational knowledge management practices (Bundgaard & Borrás, 2021; van Winden & van den Buuse, 2017). According to Van Winden and Van den Buuse (2017), scalability is understood through two main trajectories: *expansion*, referring to the institutionalization and deepening of transparency practices within existing structures, and *replication*, which refers to the transfer and adaptation of these practices across different contexts or jurisdictions.

To enable such scalability, Learnability refers to the capacity of both systems and stakeholders to acquire, share, and apply knowledge in response to evolving and responsive transparency; as Matta et al. (2025) emphasize the *"importance of integrating knowledge management, organizational learning, and open innovation networks into the upscaling strategies"*. In the IoT-TMM model, Learnability captures the essence of knowledge management but reconceptualizes it as a core capability embedded in transparency systems. Learnability encompasses processes such as reflective practice, the documentation of decisions, feedback integration, and the institutionalization of lessons learned. It ensures that transparency initiatives are not confined to isolated pilots but become part of a cumulative learning process capable of evolving across time and space (Bundgaard & Borrás, 2021; Matta et al., 2025; van Winden & van den Buuse, 2017).

Learnability thus facilitates the replication of effective models, reduces redundant experimentation, and accelerates organizational adaptation by supporting the transfer of knowledge across departments, cities, and initiatives.

Table 5 summarizes how each dimension contributes to achieving specific levels of transparency maturity

Dimension	Description
Accessibility	Accessibility is necessary for achieving the "Disclosed" level.
Usability	Usability contributes to achieving the "Comprehended" level.
Informativeness	Informativeness enables progression to "Comprehended" and "Reliable" levels.
Understandability	Understandability supports advancing to "Comprehended" and "Reliable" levels.

Dimension	Description
Audibility	Auditability is necessary to reach "Reliable" and "Participative" levels.
Learnability	Learnability contributes to reaching "Reliable" and "Participative" levels.

Table 5: A Summary of IoT-TMM Dimensions, adapted from (Cappelli et al., 2013)

4.3 IoT-TMM Practices

To systematically assess the proposed dimensions of transparency (summarized in Table 5), this study employs the Goal-Question-Operationalization (GQO) method. GQO provides a structured approach for translating abstract transparency goals into concrete practices by defining high-level objectives (goals), formulating diagnostic questions, and identifying concrete practices for evaluation. Applied to the six transparency dimensions—Accessibility, Usability, Informativeness, Understandability, Auditability, and Learnability, the GQO framework enables a comprehensive and methodologically grounded evaluation of transparency efforts.

To contextualize and embed these dimensions within key organizational dimensions, the McKinsey 7S model is adopted as a complementary analytical lens. The 7S framework distinguishes between "hard" elements—Strategy, Structure, and Systems—which are more formalized and easier to manage—and "soft" elements—Style, Staff, Skills, and Shared Values (summarized in Table 6)—which reflect cultural and human factors that shape implementation outcomes. By aligning each transparency practice with relevant 7S elements, the model ensures that operationalization is not only technically feasible but also organizationally grounded.

Table 6 presents the original definitions of the 7 factors alongside their adapted definitions for IoT transparency, the focus of this study.

	S-Factor	Definition	Adapted definition
S1	Strategy	“A plan of action designed to achieve a desired future position articulated through specific objectives and constrained by the organization’s capabilities and	The city’s plan to progress between Maturity Levels by assessing the current situation and performing a gap analysis to the targeted maturity level.

	S-Factor	Definition	Adapted definition
		potential" (Kaplan, 2005; Kumar & Geetika, 2019).	
S2	Structure	"The way in which tasks and people are specialized and divided, and authority is distributed; how activities and reporting relationships are grouped; the mechanisms by which activities in the organization are coordinated" (Kaplan, 2005; Kumar & Geetika, 2019)	How transparency-related tasks, responsibilities, and accountability are structured and coordinated across municipal units. This includes the institutional mechanisms for managing disclosure, oversight, and citizen engagement, reflecting the municipality's capacity to support participatory and scalable transparency.
S3	Systems	"The formal and informal procedures used to manage the organization, including management control systems, performance measurement and reward systems, planning, budgeting and resource allocation systems, and management information systems" (Kaplan, 2005; Kumar & Geetika, 2019).	The formal and informal processes municipalities use to manage transparency—ranging from budgeting tools, and planning frameworks to digital platforms, registries, feedback loops, and audit trails. These processes support the full information lifecycle, from data elicitation to access and oversight.
S5	Style	"the leadership style of managers; how they spend their time; what they focus attention on; how they make decisions; also, the organizational culture, that is, the dominant values and beliefs, the norms, the conscious and unconscious symbolic acts taken by leaders" (Kaplan, 2005; Kumar & Geetika, 2019).	The leadership behaviour and cultural norms that leadership approaches that promote openness, innovation, and organizational cultural readiness for transparency and data ethics. This includes Leadership commitment to openness and accountability, and whether transparency is reactive or proactive, and the tone of engagement with citizens.
S4	Staff	"The people, their backgrounds and competencies; how the organization recruits, selects, trains, socializes, manages the careers, and promotes employees" (Kaplan, 2005; Kumar & Geetika, 2019).	The human capital of the organization focuses on hiring practices, training, career development, and managing employees involved in designing, implementing, and monitoring transparency practices.
S6	Skills	"The distinctive competencies of the organization; what it does best along dimensions such as people, management practices, processes, systems, technology, and	The city's transparency capabilities include legal literacy, data stewardship, co-creation, and staff skills in ethics, privacy, and communication—supported by expert

	S-Factor	Definition	Adapted definition
		customer relationships” (Kaplan, 2005; Kumar & Geetika, 2019).	involvement and targeted training to advance maturity.
S7	Shared Values	“The core or fundamental set of values that are widely shared in the organization and serve as guiding principles of what is important; vision, mission, and values statements that provide a broad sense of purpose for all employees” (Kaplan, 2005; Kumar & Geetika, 2019).	Anchors the organization around shared principles of data transparency—such as trust, accountability, inclusivity, fairness, and democratic participation—that are embedded across departments and stakeholder relationships.

Table 6: McKinsey 7S Framework (adapted)

In the context of this study, the "Opaque" level is conceptually defined by the absence of transparency. At this baseline stage, transparency is either entirely lacking or limited to reactive, unstructured responses. Consequently, attempting to define operationalized practices at this level is inherently contradictory: operationalization concerns the intentional and structured actions taken to realize transparency goals, and such actions are by definition not present in an opaque environment.

Therefore, the process of operationalization within the maturity model logically begins at the "Disclosed" level—the first stage where transparency is acknowledged as a goal and initial steps are taken to act upon it. From this level onward, organizations begin to engage in defined, if basic, activities to increase transparency. These actions then evolve across subsequent stages—"Comprehended," "Reliable," and "Participatory"—which represent progressively deeper and more participatory engagements with transparency principles.

At each of these levels, the GQO framework allows for the systematic identification of "how" transparency is being operationalized across each dimension. These include, for example, practices related to the publication of data, mechanisms for ensuring its interpretability and contextual relevance, and processes for stakeholder feedback and co-decision-making.

The following tables present a structured synthesis of the identified practices across the six dimensions of the IoT-TMM. Each table aligns specific practices with the model’s operational goals, diagnostic questions, and the associated organizational “S-factors” (Structure, Style, Skills, Systems, Staff, and Shared Values). The tables draw on both literature and interviews to illustrate how transparency can be operationalized in practical, actionable ways across municipal contexts.

Tables 7–12 elaborate on each dimension individually, beginning below with Accessibility, followed by Usability, Informativeness, Understandability, Auditability and Learnability (Table 6 provides a summary of the six dimensions).

Accessibility

Goal	Ensure the public can retrieve IoT governance from multiple sources in smart cities.
Question	How is information elicited, accessed, and managed across its lifecycle—from elicitation to publishing?

Operationalization	S-factor	Sources
Co-design data elicitation protocols with public stakeholders, e.g., through workshops or civic hackathons, to decide what data should be collected, from whom, and how.	Style	(David et al., 2015; Krukowski & Raczyńska, 2019; Matheus et al., 2023; Interviews)
Defining roles and responsibilities, such as a project manager and a team for transparency practices.	Structure	(Krukowski & Raczyńska, 2019; Interviews)
Establish shared governance roles, including citizen oversight panels, community liaisons, and participatory audit groups		
Create inclusive, multimodal access points (APIs, web portals, physical signage, mobile apps, chatbots, etc.) with feedback loops integrated at each point of access.	Systems	(Bertot et al., 2010; Cucciniello et al., 2016; Lnenicka & Nikiforova, 2021)
Implement participatory digital platforms (forums, ideation platforms) where residents can propose, vote on, and prioritize transparency-related improvements.	Shared Value; Style	(David et al., 2015; Matheus et al., 2023)
Availability of automated updates.	Systems	(Long et al., 2024)
Apply Accessibility standards WCAG.	Skills, Systems	(Bastardo & Rocha, 2024; Krukowski & Raczyńska, 2019; Oliveira et al., 2016; Interviews)
Use automated tools, such as Lighthouse tool developed by Google, to measure web accessibility	System	(Baldo et al., 2023)
Automate opening of relevant information for the public using API based	System	(Long et al., 2024)

Table 7: Accessibility Practices

Usability

Goal	Ensure that users can easily navigate and interact with transparency tools.	
Question	How easy is it for the public to navigate and reach information about public sensors/IoT data use and privacy policies that affect their activities?	
Operationalization	S-Factor	Sources
Conduct initial observations of users interacting with the basic portal to identify immediate usability issues, via for example, co-design labs where users participate directly.	Style; Skills; Shared Value	(Barcellos et al., 2022; Bastardo & Rocha, 2024; Lnenicka et al., 2022; Lnenicka & Nikiforova, 2021; Matheus et al., 2023; Murmann & Fischer-Hubner, 2017)
Regularly update designs based on performance metrics (e.g., error rates, task efficiency) and user feedback.	System	
Use self-explanatory and standard icons to aid recognition, such as color coding to emphasize the meaning of text and graphics, such as using red for critical states.		
Allow customizable data views, including filters and sorting options.	System	(Matheus et al., 2023)
Design portals with a user-centred architecture that includes a clear and logical menu structure, effective keyword search and filtering capabilities, and consistent cross-device functionality (desktop, tablet, smartphone). Enhance data discoverability and interpretability through intuitive visualizations (e.g., maps, charts, infographics) and descriptive metadata (titles, sources, usage explanations) that allow users to quickly assess relevance and meaning.	System	(Gagliardi et al., 2017; Lnenicka & Nikiforova, 2021)
Tailor interfaces and content to reflect the specific cultural, linguistic, and social characteristics of the urban population to enhance accessibility and relevance.	System	(David et al., 2015)
Integrate gamification to encourage continued engagement and use of applications.	Style	(Bastardo & Rocha, 2024)

Table 8: Usability Practices

Informativeness

Goal	Provide the public with clear, structured, contextualized, and meaningful information.	
Question	How well is data explained, contextualized, and relevant?	
Operationalization	S-Factor	Source

Goal	Provide the public with clear, structured, contextualized, and meaningful information.	
Ensure raw data is downloadable in various formats (e.g., CSV, JSON).	Systems	(Matheus et al., 2023; Suzor et al., 2019)
Provide Help and Support Sections, FAQs, tutorials, contextual information, layered details, version-controlled records, and metadata to support understanding.	System/ skills	(Barcellos et al., 2022; Matheus et al., 2023) Interviews
Conduct and publish Privacy Impact Assessments (PIAs).	Structure	(Urquhart et al., 2019)
Offer both pre-defined apps and websites (functionalities), including interactive data visualization tools to improve comprehension, and raw data portals (open datasets) to serve varied user groups.	Systems / Skills	(Matheus et al., 2023)
Provide versioning and historical records (e.g., policy timelines).	System	(Murmann & Fischer-Hubner, 2017)
Use analytics to assess content effectiveness.	Systems	
Visualize data privacy risks with different frameworks.	Style/skills/ System	
Measure informativeness by assessing metadata completeness, privacy disclosures, and traceability.	System	(Urquhart et al., 2019)
Adopt standardized metadata frameworks (e.g., DCAT) and present key information.	System	(Barcellos et al., 2022; Matheus et al., 2023; Murmann & Fischer-Hubner, 2017)
Implement multilayered visualizations (e.g., map with expandable details).	System/ Style	
Provide contextual explanations of data collection, use, reuse, retention, and processing	Skills/Style	
Continuously adapt the content based on information architecture and user comprehension research, including public feedback.	Skills/ Shared Value	(David et al., 2015; Matheus et al., 2023; Interviews)
Primarily use plain language to describe basic sensor details and policies, focusing on clarity and avoiding terms that might not be self-explanatory	System/ Skills/Style	
Conduct initial, informal feedback to gauge if the basic information aligns with user expectations.	Style/ Shared Value	

Table 9: Informativeness Practices

Understandability

Goal	Enhance public awareness and understandability regardless of their background.	
Question	How to enhance the public data literacy and awareness of data practices?	
Operationalization	S-Factor	Source

Goal	Enhance public awareness and understandability regardless of their background.		
Provide interactive (AI-powered) policy explainer.		Systems/Skills	(Long et al., 2024)
Provide educational resources, digital literacy programs, and community-building tools that empower citizens to participate meaningfully in governance processes		Shared Value/Skills	(David et al., 2015)
Develop privacy glossaries and FAQs to clarify technical terms that might not be self-explanatory (e.g., distinguishing between sensor types or data identifiers).		Skills/Style	(Murmann & Fischer-Hubner, 2017)
Conduct user evaluations (e.g., short questionnaires) to assess initial user comprehension of the presented information and identify any deviations from their mental models.		Structure/Skills	(Murmann & Fischer-Hubner, 2017)
Conduct human-led public awareness campaigns explaining types of sensors, intended use, privacy risks, and how to interpret sensor data (e.g., sensor safaris and/or data walks).		Shred Value/Style	(David et al., 2015; Shaffer, 2023; Interviews)
Utilize advanced technologies such as gaming to allow for interactive information and learning.		Style/Skills	(Bastardo & Rocha, 2024)
Deploy information points.		Shared Value/Skills	(Shaffer, 2023)

Table 10: Understandability Practices

Auditability

Goal	Enable the verification and enforcement of privacy commitments through systematic reviews, audits, and external oversight.		
Question	How easy to identify violations of information about IoT intended data use policies?		
Operationalization		S-Factor	Source
Require periodic third-party privacy audits to verify compliance with regulations.		Structure/ System	(Williams, 2015; Interviews)
Enable citizen-driven audits using participatory reporting (i.e., use of technologies such as crowdsourcing to allow citizens to report on urban problems		Style/ Shared Value/ System	(Bastos et al., 2022)
Implement blockchain-based audit trails for immutable and transparent logs.		System	(Bastardo & Rocha, 2024)
Design and Implement accountability and feedback mechanism.		Structure/ System	(Baldo et al., 2023)
Ensure that transparency mechanisms allow citizen input and institutional response (feedback channels, co-design).		Style/Share d Value	(David et al., 2015)

Goal	Enable the verification and enforcement of privacy commitments through systematic reviews, audits, and external oversight.	
Introduce residents engagement tools for flagging inaccuracies, reporting violations, and suggesting transparency improvements.	Style/Shared Value	(Bastos et al., 2022)
Implement AI-driven policy compliance checks to detect risks, gaps, or missing disclosures.	System	(Urquhart et al., 2019)
Establish transparency KPIs (e.g., disclosure quality, clarity, completeness, engagement rate).	Strategy/ Systems	
Define a crisis response team to monitor and respond to identified data and privacy risks.	Structure / Staff	
Involve civic groups and residents in IoT deployment audits and monitoring.	Shared Value/ Style	(Bastardo & Rocha, 2024; Bastos et al., 2022; David et al., 2015)
Use gamified tools and crowdsourcing to enable the public to add, monitor, flag, or report sensor data and placement.	Style/Skills	

Table 11: Auditability Practices

Learnability

Goal	Establish and maintain a robust system for capturing, sharing, and utilizing knowledge related to sensor transparency within the organization and with external stakeholders.	
Question	How is knowledge about transparency processes, best practices, and public feedback managed and disseminated to continuously improve transparency efforts?	
Operationalization	S-Factor	Source
Integrate public feedback for improving transparency.	Style/System	(Barcellos et al., 2022; Matheus et al., 2023)
Encourage documentation of transparency-related processes.	System	
Conduct internal training on disclosure and privacy principles and requirements.	Skills/Staff	
Develop knowledge-sharing protocols with other municipalities and the federal government.	Structure/Strategy	Interviews
Monitor knowledge usage and sharing metrics to assess impact.	System	
Regularly update knowledge assets based on user feedback and evolving best practices.	System/Skills	
Join a consortium with other municipalities, researchers, and civic groups for knowledge sharing, setting best practices, interoperability standards, and mentoring other bodies.	Structure / Shared Value	Interviews

Goal	Establish and maintain a robust system for capturing, sharing, and utilizing knowledge related to sensor transparency within the organization and with external stakeholders.	
Cultivate a culture that values continuous learning and knowledge sharing across all stakeholders.	Shared Values / Style	
Innovate knowledge management practices to adapt to organizational changes and emerging challenges in sensor transparency	Strategy / Systems	

Table 12: Learnability Practices

4.4 IoT-TMM Model

As previously mentioned, the design of the IoT-TMM is fundamentally grounded in the maturity model developed by Cappelli et al. (2013), which provides a structured and progressive framework for assessing and enhancing organizational capabilities. Building on this foundation, the IoT-TMM adapts and extends the outcome based Cappelli's transparency qualities to specific practices and to the context of IoT in smart cities.

To enrich this foundation, the model integrates insights from the frameworks developed by Matheus and Janssen (2015, 2020) and Matheus et al. (2021), which conceptualize transparency as a cyclical process beginning with the elicitation of public data needs and culminating in the communication of results and informed action. These frameworks emphasize that transparency is not a one-time event but an ongoing relationship between governments and residents.

Further, the IoT-TMM is informed by the dynamic capabilities' perspective of Teece (2016). In this light, the model enables municipalities to *sense* public expectations (e.g., via participatory mechanisms), *seize* these insights by incorporating them into actions and communication, and *transform* institutional routines and systems through organizational learning and cross-departmental collaboration.

IoT-TMM description

At the starting point, Opaque, transparency is either reactive or entirely absent. Accessibility at this stage is one-time off or limited to general inquiries handled through emails or phone calls, without any structured disclosure mechanism. There are no specific usability tools to assist users, and information, when provided, is often delivered in unstructured, jargon-heavy textual formats. Auditability mechanisms are non-existent, and citizens have no way of verifying or contesting the information—or even knowing that it exists. Likewise, organizational Learnability is absent, with no training, documentation, or feedback processes in place. In this context, transparency is nobody's responsibility, and public access to crucial information about IoT deployments and privacy policies remains severely restricted.

As organizations take their first steps toward transparency, they reach the Disclosed level. At this stage, the focus shifts from reactive opacity to intentional, though still limited, disclosure efforts. Municipalities begin to identify key stakeholders, establish internal project teams, and define preliminary transparency goals. Crucially, this level also marks the initial emergence of "Sensing" capabilities: early attempts to recognize and respond to public expectations—often through workshops, consultations, or surveys—reflect an acknowledgment of the need to elicit data needs from citizens.

Basic transparency infrastructures—such as sensor registries or open data portals—are typically established during this phase, albeit with minimal functionality and often without substantial user engagement. While technical accessibility improves through the publication of data and information, public awareness and actual usage remain limited due to weak promotion and lack of contextual framing. Usability progresses modestly, with features like search bars or filters introduced, though interfaces are rarely intuitive or inclusive. Informativeness increases slightly through the inclusion of basic metadata, but content often remains static, overly technical, and poorly aligned with every day public concerns.

Initial steps toward auditability appear, such as the appointment of transparency officers or basic internal tracking mechanisms, yet formal oversight and verification procedures are often underdeveloped. Learnability surfaces through sporadic documentation efforts or pilot feedback loops, but these are rarely institutionalized or evaluated systematically. Overall, while the Disclosed level signals an important shift toward "Seizing" transparency opportunities, practices are still fragmented and symbolically driven. The lack of dynamic feedback loops and strategic adaptation means that transparency, though improving in visibility, is not yet transformative in practice.

Building on these early efforts, organizations that commit to structured improvements advance to the Comprehended level. Transparency here becomes more intentional and user oriented. Accessibility is enhanced through the introduction of multiple information formats—text, icons, signage, QR codes—and the adoption of basic accessibility standards (WCAG-A). Dedicated transparency officers oversee disclosure efforts, ensuring continuity and ownership. Usability significantly improves through the application of structured information models, making navigation and interpretation easier for diverse audiences. Informativeness is deepened with standardized metadata frameworks such as DCAT, offering clearer explanations about data collection, usage, reuse, and privacy implications. Understandability is prioritized by organizing human-led awareness campaigns, developing glossaries, FAQs, and simplifying language to cater to different literacy levels. Auditability is strengthened through citizen engagement mechanisms that allow users to flag inaccuracies or propose improvements. Simultaneously, Learnability practices mature, with centralized repositories and lessons-learned processes institutionalized. Nevertheless, decision-making at this stage tends to remain largely top-down, with limited integration of citizen participation into governance structures.

As transparency processes mature further, municipalities reach the Reliable level, where transparency becomes embedded into institutional structures rather than isolated projects. Accessibility is institutionalized through standardized, automated APIs that ensure continuous updates and greater public accessibility, including adherence to higher accessibility standards (WCAG-AA). Usability becomes dynamic, with regular usability testing and iterative interface redesigns based on citizen feedback and user research. Informativeness is measured and monitored, with version control, historical data, and quality analytics ensuring ongoing relevance and accuracy. Understandability is enhanced through AI-driven policy explainers that adapt to user profiles, making even complex data accessible to non-experts. Auditability transforms into an active, AI-supported compliance monitoring system, including Privacy Impact Assessments and clear Key Performance Indicators (KPIs) for data quality and policy clarity. Learnability is no longer ad hoc but strategically integrated, with standardized practices for sharing, updating, and utilizing organizational knowledge. At this stage, citizen feedback starts to significantly influence transparency practices, although ultimate decision-making authority often still resides with governmental actors.

Ultimately, at the Participatory level, transparency becomes a truly collaborative and continuously evolving capability. Accessibility is maximized through full WCAG-AAA compliance and through partnerships with communities to co-create new accessibility options. Usability is dynamically co-designed in living labs and citizen workshops, ensuring that portals, apps, and signage respond directly to user needs and experiences. Informativeness is continuously adapted and co-created with citizens, ensuring that data-use policies are not just explained but jointly developed and annotated. Understandability reaches its highest maturity, using interactive technologies like gamification and personalized AI risk-explainers to make complex information intuitive and engaging. Auditability becomes deeply participatory: citizens and civic groups co-monitor sensor deployments, flag discrepancies, suggest improvements, and engage in participatory audits. Learnability evolves into an ecosystem of shared learning, with municipalities forming consortia with researchers, civil society, and other governmental bodies to establish best practices, mentor others, and drive continuous innovation.

Thus, the IoT-TMM presents transparency not as a static goal, but as a dynamic and relational process—one that grows through increasing levels of citizen engagement, technological sophistication, and organizational learning. Moving from opacity to participatory transparency requires not just technical reforms, but a fundamental reimagining of transparency as shared governance, where citizens are empowered not merely to observe, but to shape, question, and co-create the smart city environments they inhabit.

Table 13 summarizes the defining features and progression of each maturity level across the six dimensions of transparency.

IoT-TMM Matrix

	Opaque	Disclosed	Comprehended	Reliable	Participatory
Overview	Transparency is reactive or does not exist.	Basic transparency is rolled out.	Transparency is structured and expanded.	Transparency scales beyond individual projects.	Transparency is co-created and replicated.
Accessibility	Inquiries handled through ad hoc emails or phone calls.	-Identify stakeholders and elicit transparency needs, requirements, and challenges. -Build a team and assign roles. -Identify procedures for eliciting and publishing privacy policies (ex: a registry) -Identify technology requirements, i.e. an app vs portal and/or in-house vs SaaS.	-Designate transparency officers. -Introduce multi-formats, such as texts, pictures, icons, signage, QR codes, APIs or others. -Adopt WCAG-A standards.	-Automate disclosure process (via API) from other databases, i.e. assets management. -Define change management process. -Adopt WCAG-AA standards.	-Co-create accessibility features with communities -Disclose decision-making processes for deployments. -Foster a culture that prioritizes high-quality information sharing. -Adopt WCAG-AAA standards.
Usability	-	-Launch basic portal with basic usability requirements, such as search, filter, maps, feedback. -Define acceptable response time, error rate, and other relevant usability metrics.	-Structure information using an information model.	-Iterate designs based on usability and readability testing. -Implement reliability metrics for content and interaction.	-co-design interfaces with users via design labs -continuously improve usability based on usability research.
Informativeness	Information is informal and lacks structure.	-Classify and profile sensors according to their privacy risk. -Develop basic metadata (sensor type, location, purpose, owner), besides textual format of policies and reports, such as pdfs.	-Adopt standardized frameworks (e.g., DCAT) -Provide clear and contextual explanations of data collection, intended use, re-use, retention, and processing.	-Provide versioning/historical records of how IoT policies change over time. -Assess content effectiveness. -Implement data quality metrics. -Identify and communicate privacy risks.	-Co-develop privacy policies with the public. -Continuously refine content based on information architecture and user comprehension research.

Understandability	Texts jargon-heavy and lengthy.	Texts are simplified but still contain jargon and lengthy.	-Conduct human-led public awareness campaigns explaining types of sensors, intended use, privacy risks, and how to interpret sensor data. -deploy information points -Use plain language, glossaries, and FAQs to clarify technical terms.	-Deploy AI-powered policy explainer chatbots. -Deploy AI to tailor transparency data explanations based on user profiles (e.g., technical experts vs. general public). -Implement readability standards.	-Use predictive and risk-sensing capabilities using AI-risk assessment. -Utilize advanced technologies such as gaming to allow for interactive information.
Auditability	No audit mechanism defined.	-Assign transparency officers to oversee data-use documentation efforts. -Identify disclosure requirements. -Identify internal audit process	-Introduce public engagement tools for adding missing sensors, flagging inaccuracies, suggesting transparency improvements, and reporting violations.	-Use AI-driven policy compliance checks to detect critical and missing disclosure data, and identify risks of privacy breaches, misuse, or harms. -Conduct and publish Privacy Impact Assessments (PIAs) for deployments. -Define KPIs for transparency such as the rate of interaction with disclosed data. -Define a crisis response team to monitor and respond to identified risk.	-IoT deployment and privacy become audited by policymakers, civic groups, and residents. -engage communities before deployments. -Use gaming to tap into the public capabilities to add, monitor, flag, and report sensors. -Residents can contribute data and verify sensor placement and currency via crowdsourcing.
Learnability	-	-Collect Public's feedback. -Document procedures and lessons learned. -Conduct internal training on disclosure and privacy principles and requirements.	-Train employees on identifying and responding to privacy issues and inquiries. -Integrate feedback and lessons learned into process improvement cycle. -Implement centralized knowledge repositories. -Standardize documentation practices.	-Develop basic knowledge-sharing protocols with peer cities and federal government. -Monitor knowledge use and sharing. -Regularly update knowledge assets based on user feedback.	-Join a consortium with peer cities, federal government, researchers, and civic groups, for knowledge sharing, setting best practices, interoperability standards, and mentoring other bodies. -Cultivate a culture that values continuous learning and knowledge sharing. -Foster innovative knowledge management practices to adapt to organizational changes.

Outcomes	Transparency is nobody's responsibility. The public has limited or no access to where IoT sensors are placed, what data is collected, how it is used, or to the deployment decision-making. There is a lack of process awareness manifested by a lack of employees' knowledge of the processes, or a lack of identified processes	✓ Basic disclosure data (such as sensors locations and types) is accessible via portal but remains static, incomplete, unstructured, or not regularly updated, and with limited usability functions, such as filters. ✓ Some processes exist and are repeatable but are inconsistent, not updated, or project based. ✓ A project team is assigned to establish core processes. ✓ Compliance mechanisms may exist, but audits are not feasible. ✓ Awareness of the need to implement process-based solutions exists. ✓ clear division of responsibilities in the execution of basic processes. ✗ Texts contain technical and legal jargon, limiting comprehension. ✗ Not all identified processes are implemented. ✗ improvisation of process execution exists. ✗ Major barriers exist for users with disabilities, making it challenging to access any content. ✗ The organization starts gathering information related to user experiences and expectations, but implementation may still be inconsistent.	✓ Transparency processes are well-defined, repeatable, and include clear responsibilities, accountability structures, and disclosure mechanisms. ✓ An information model is in place, incorporating metadata and a defined RACI (Responsible, Accountable, Consulted, Informed) matrix. ✓ Disclosed data are structured and intuitive, enabling citizens to understand privacy implications. ✓ The public has access to clear explanations of IoT data usage; however, decision-making remains largely top-down with limited opportunities for participation. ✓ Transparency adapts to varying literacy levels through tools like signage, QR codes, and high-level summaries. ✓ Interactive initiatives, such as "sensor safaris/data walks" help raise public awareness. ✓ Public awareness of IoT transparency rights is gradually increasing. ✓ Partial compliance with WCAG standards, some accessibility issues are present for people with disabilities.	✓ Policies are systematically disclosed and measured through performance metrics, with audit mechanisms ensuring compliance. ✓ Transparency is delivered through a multi-channel approach, including physical signage, QR codes, living labs, and interactive initiatives like sensor safaris, as well as gaming. ✓ Governance documentation is well-structured, with API-based policy collection and updates ensuring currency, consistency, and accessibility. ✓ The public can understand privacy implications and actively contribute to improving the clarity and usability of transparency information. ✓ Transparency platforms are widely used by the public, adapting to user needs and literacy levels. ✓ Public feedback is integrated into IoT governance, with evidence-based decision-making regularly reviewed for accuracy, privacy protection, and ethical compliance. ✓ A long-term institutional memory and knowledge-sharing repository support sustainable governance. ✓ Standardized and continuously monitored processes exist for data collection, reporting, and verification. ✓ Public participation is embedded in audits and feedback loops. ✓ Partial compliance with WCAG standards, some accessibility issues are present for people with disabilities.	✓ Decision-making is participatory, with a structured knowledge management strategy and policies in place. ✓ IoT privacy policies and deployments are co-governed by policymakers, civic groups, and residents. ✓ Transparency becomes a collaborative and adaptive process, continuously evolving based on public input. ✓ The public actively co-design transparency systems, contributing to participatory audits and policy recommendations. ✓ Information, model, format, and structure are standardized across organizations. ✓ Transparency lifecycle is fully mapped (eliciting, collecting, publishing, using, and sharing). ✓ Content is accessible to all users, including those with disabilities.

Table 13: IoT-TMM Matrix

5 Results

To assess the relevance and applicability of the proposed IoT-TMM, feedback was solicited from stakeholders with practical experience with IoT transparency and actively engaged in in smart cities initiatives (see section 3.1 for detailed roles). Additionally, preliminary case studies were conducted with three Dutch municipalities. The validation process combined qualitative insights from interviews and a self-assessment of municipal practices using the model's six key dimensions (Ajoudanian & Aboutalebi, 2025; Suliman et al., 2020). This multi-source validation approach informed the refinement of the model and helped validate its potential for real-world application ensuring both theoretical soundness and practical usability.

5.1 Experts feedback

Three experts provided valuable insights, The first expert offered strong positive feedback, describing the model as *"a complete, yet comprehensive and well-readable model to assess maturity in transparency of public organizations."* They emphasized its practical relevance, noting that while their organization had already undertaken efforts such as the development of sensor registries, the model highlighted further opportunities for growth. This suggests that the model is effective in prompting internal reflection and guiding transparency strategies. The expert also expressed interest in sharing the final model with their team, indicating its perceived usefulness in organizational practice.

The second expert provided a more critical perspective, acknowledging the model's depth but suggesting it could initially appear complex to public sector users. They offered three core suggestions:

1. Broader Scope of Transparency: They recommended situating sensor-related transparency within the wider context of transparency.

2. Clarification of Participation: They highlighted the importance of distinguishing between participation and transparency, emphasizing that transparency should facilitate participation through adequate and accessible information.

3. User-Centered Focus: They stressed that transparency is only meaningful if it resonates with and is utilized by residents, urging greater attention to community needs and preferred formats of information.

Finally, a smart city architect who organized a public “sensor safari” tour—designed to raise awareness of data collection practices and sensor use—responded that “*it was a great tour evaluating the many dilemmas and issues your model suggests.”* Although the researcher could not attend the tour, this feedback underscores that the model successfully reflects the real-world dilemmas and challenges faced by practitioners engaging the public on IoT systems. It highlights the model's resonance with outreach and literacy-raising efforts.

The feedback gathered during validation led to several important refinements of the IoT-TMM. Based on expert input, the model was restructured to better emphasize the role of accessible and actionable information as a foundation for enabling meaningful engagement. A user-centered perspective was embedded more explicitly across all maturity levels, highlighting the importance of understanding and responding to citizen needs and literacy levels. Furthermore, while the model was initially developed with a focus on IoT-related data collection and usage, the validation process revealed that its structure and dimensions can be equally applicable to broader transparency initiatives beyond IoT. As a result, the model was refined to allow flexible use across different digitalization efforts of public sector, without compromising its specificity for smart cities IoT contexts.

5.2 Case Studies

This section presents the results of applying the IoT-TMM to the selected case studies: Amsterdam, The Hague, and the province of Brabant. The assessment for each governmental entity was meticulously derived from a multi-faceted approach, integrating insights from publicly available information, such as official websites, and published reports; expert interviews with city officials responsible for IoT deployments and data governance; and further substantiated through the analysis of relevant documents provided by the experts during and after the interviews. This comprehensive data collection methodology allowed for a robust and nuanced evaluation of each dimension against the IoT-TMM's maturity levels

As previously discussed, in section 3.5, the selection of Amsterdam, The Hague, and Brabant as cases for this study was intentional, based on variations in size and resources, which offer a range of perspectives on the challenges and opportunities of smart city transparency initiatives. Amsterdam, as a large urban center with extensive resources, represents a model of a highly developed smart city ecosystem, where the scale of operations allows for sophisticated infrastructure and data management systems. The

Hague, as a medium-sized city, offers insights into the experiences of municipalities that may face moderate resources, providing a more balanced perspective between large cities and smaller regions. The province of Brabant, being a smaller province, provides a unique view of how transparency initiatives can be scaled and adapted to less resource-rich environments, where challenges related to implementation and sustainability may be more pronounced. By including these three different organizational scales, this study captures a comprehensive spectrum of smart city governance, allowing for a nuanced analysis of how transparency frameworks function across varying levels of infrastructure and capacity.

Amsterdam

The assessment provided for Amsterdam often highlights progress but also points to limitations or areas for improvement. Amsterdam has a proactive and structured approach to transparency, marked by accessible public registries and the provision of metadata. These efforts indicate a move beyond the initial rollout of transparency (Disclosed) toward a clearly defined and expanding transparency framework. Nonetheless, limited public awareness constrains transparency from reaching the Reliable level, where transparency is broadly scaled and deeply embedded in city-wide practices. Therefore, evidence suggests that, overall, it operates at the Comprehended level.

Accessibility

Amsterdam's public online sensor registry reflects a *Comprehended* level of accessibility. The availability of an online portal with defined procedures for publishing sensor-related policies and technology requirements shows the city's commitment to accessible transparency, which are elements of the Disclosed level for Accessibility. The efforts in accessibility (public registry), informativeness (metadata), and understandability (simplified descriptions, signage) all point to transparency being structured and expanded, which are key characteristics of the Comprehended level. The limited public awareness, however, diminishes effective accessibility, preventing the city from achieving the *Reliable* level, which would require broader adoption, automation, and well-established change management processes.

Usability

The usability dimension remains at the *Disclosed* level. While users can navigate the available information through basic tools such as search and filters, there is a recognized need for improvement in interface design and reporting mechanisms. These enhancements would encourage active use and regular updating, essential features of the Reliable level that Amsterdam has yet to fully implement. It also doesn't have a fully developed and structured information model required to achieve Comprehended level.

Informativeness

Amsterdam meets the *Disclosed* level in informativeness. The sensor registry provides basic metadata including ownership, purpose, and privacy statements, which help contextualize the intended use of sensors and data. However, incompleteness in some entries signals gaps in data quality and the absence of fully structured metadata, hinders advancement to the Comprehended level.

Understandability

Efforts to improve understandability through signage, icons, and human-led public awareness campaigns —piloted by initiatives like the Responsible Sensing Lab—align with the *Comprehended* level. These activities make technical information more accessible to the public. Yet, the city recognizes that sustained public outreach and broader knowledge dissemination are necessary to fully build public literacy, which is critical for reaching the Reliable level.

Auditability

Audit processes are currently at the *Disclosed* level, hindered by weak formal mechanisms for verifying sensor registration accuracy and acknowledged internal non-compliance. The city itself acknowledges internal non-compliance which strongly indicates a lack of effective audit processes beyond basic identification. This lack of effective verification tools or public engagement mechanisms limits auditability from advancing to higher maturity levels. The city's awareness of their Auditability requirements makes it progress to the Disclosed level.

Learnability

Learnability is assessed at the *Comprehended* level. Feedback loops and lessons learned from the sensor registry and signage experiments contribute to ongoing improvements. The signage experiments also point to internal capacity-building efforts, such as training employees to identify and respond to privacy concerns. Importantly, Amsterdam participates in a broader consortium aimed at sharing knowledge and practices across cities, which supports cross-institutional learning. However, the more advanced aspects of *Reliable* learnability—such as formalized protocols for knowledge exchange, consistent monitoring of how knowledge is used, and routine updates based on user feedback—are not yet fully institutionalized or scaled.

In summary, Amsterdam's transparency initiatives demonstrate a solid foundation across all dimensions, generally aligning with the *Comprehended* level of maturity. However, the transition to *Reliable* transparency requires scaling up outreach, automating processes, improving data completeness, and strengthening audit and usability mechanisms.

To consolidate the findings of Amsterdam's assessment, the following, Table 14, summarizes the city's maturity level across the six dimensions of the IoT-TMM. Each dimension is accompanied by a brief justification, reflecting both documented practices and limitations.

Dimension	Level	Assessment
Accessibility	Comprehended	The sensor registry is publicly available online. However, limited public awareness reduces actual accessibility.
Usability	Disclosed	Users can navigate information, but the interface and reporting processes could be improved to encourage active use and updating.
Informativeness	Disclosed	The registry includes metadata like ownership, purpose, and privacy statements, although some entries are incomplete.
Understandability	Comprehended	Efforts such as signage, icons, and simplified descriptions are piloted (via the Responsible Sensing Lab), making technical information more approachable.
Auditability	Disclosed	Formal mechanisms for verifying sensor registration accuracy are weak. The city itself acknowledges internal non-compliance.
Learnability	Comprehended	Feedback loops and lessons learned from the sensor registry and signage experiments contribute to ongoing improvements.

Table 14: A Summary of Amsterdam Assessment

The Hague

The Hague represents a mid-sized city with moderate smart city investment and a more policy-driven approach. The assessment shows a focus on formal compliance rather than citizen empowerment. The information provided for The Hague generally points to a less mature state across several dimensions, often indicating an "Opaque" or "Disclosed" level. Accessibility and Usability are technically enabled but suffer from limited public awareness and suboptimal interface design. The information provided is highly technical and dense with minimal simplification—hallmarks of the *Opaque* level in both informativeness and understandability. Furthermore, the absence of mechanisms for verification or feedback underscores a lack of auditability and learnability. Therefore, transparency is present in form, but not in function.

Accessibility

The existence of a publicly available online sensor registry fulfills the basic requirement for the *Disclosed* level. This suggests that technical mechanisms and procedures for publishing privacy-related information (such as portals or registries) have been implemented. However, the assessment also indicates there is limited public awareness which significantly hinders effective accessibility. Without complementary efforts such as communication campaigns, adherence to accessibility standards (e.g., WCAG), or multiple access formats, the registry's mere existence does not translate into inclusive or meaningful public access. Thus, the city falls short of the *Comprehended* level, which demands proactive measures to ensure the information is truly accessible and usable by diverse audiences.

Usability

Users can navigate information, which means a basic digital interface that meets elementary usability requirements exist. This aligns with the Disclosed level, indicating that the infrastructure enables some degree of user interaction. However, the remark the Search functionalities could be improved to encourage active use and updating. These missing components are essential for reaching the Comprehended or Reliable levels, which focus on usability by design and continuous improvement.

Informativeness

While the content may be accurate, its presentation is dense and specialist-oriented, which limits public interpretability. This aligns with the Opaque level, where information may exist but is informal, unstructured, or presented in ways that do not support lay understanding. The absence of metadata, categorization, contextual explanations, or layered content design prevents the city from reaching the Disclosed level, where basic structuring of data are expected.

Understandability

The information is more " policy-driven" and less oriented toward lay understanding. Texts are jargon-heavy and length, which is a characteristic of the Opaque level, where documents are lengthy, technical, and not adapted to varying levels of digital literacy. To achieve the Disclosed or Comprehended levels, communications would need to be rewritten in simplified language, include FAQs, and adopt plain language principles.

Auditability

The lack of feedback channels, audit logs, or public participation tools matches the Opaque level, where no internal or external audit mechanisms are defined. In contrast, the Disclosed level requires at least basic audit mechanisms or reporting structures to be in place, and the Comprehended level involves public-facing tools for reviewing, flagging, or contributing to data accuracy. The Hague shows no evidence of these elements.

Learnability

There are no feedback loops, internal reviews, trainings, or documented learning processes that help improve transparency practices over time. Reaching the Disclosed level would require basic structures for reflection and knowledge capture, while Comprehended and above would include participatory learning and adaptation processes. The absence of even initial efforts justifies the lowest level of maturity.

Table 15 presents a summary of the Hague's performance, highlighting the areas where transparency efforts are nascent or in need of significant enhancement.

Dimension	Level	Assessment
Accessibility	Disclosed	The sensor registry is publicly available online. However, limited public awareness reduces actual accessibility.
Usability	Disclosed	Users can navigate information, but the search functionality and interface could be improved to encourage active use and updating.
Informativeness	Opaque	Available information tends to be technical, textual heavy, and less tailored to everyday users.
Understandability	Opaque	Communications about digital initiatives are more policy-driven and less oriented toward lay understanding
Auditability	Opaque	No publicly visible mechanisms exist for residents to verify sensor deployments or related data uses.

Dimension	Level	Assessment
Learnability	Opaque	No systematic effort yet exists for organizational learning or to receive or integrate the public feedback.

Table 15: A Summary of The Hague Assessment

The province of Brabant

Brabant, a provincial authority, illustrates the challenge of developing transparency practices in a limited-resource setting. Despite this, promising efforts were identified in piloting sensor registries and internal audits.

Accessibility

The presence of a public sensor registry and inventory for internal use confirms that the province has initiated technical mechanisms and internal procedures for organizing transparency. This aligns with the *Disclosed* level, which assumes an organization has moved beyond ad hoc or opaque practices by developing tools and identifying key data governance components. However, the province has not yet ensured inclusivity through open access, universal design (e.g., WCAG), or active dissemination. These are core indicators of the *Comprehended* level and remain unmet.

Usability

The province uses WeCity SaaS solution for their public registry which offers basic search functionality in its public-facing interface, indicating initial compliance with usability norms such as search or filter functions—hallmarks of the Disclosed level. The portal allows users to locate information, even if in a limited, minimally interactive way.

Informativeness

Basic information model exists but technical language dominates, which places the province of Brabant in the Disclosed category. A foundational classification of sensor data exists. Yet, informativeness remains constrained by the dominance of specialists and technical language, preventing public comprehension. This precludes advancement to the Comprehended level, which demands user-oriented explanations, adoption of standards (e.g., DCAT), and contextual clarity.

Understandability

While information may be technically correct, it lacks adaptation for public understanding, this places the province at the *Opaque* level. There's no evidence of simplified language, visualization tools, or audience-specific messaging. Without such efforts, the information remains inaccessible to non-expert users, justifying the lowest maturity classification.

Auditability

The province of Brabant maintains internal audit and assets tracking mechanisms, to track sensors deployed by the provincial government. This demonstrates internal audit efforts, which meet the criteria of the Disclosed level of setting up internal auditing responsibilities and traceability of deployments. However, the absence of public-facing mechanisms is critical, and that hinders progressing into Comprehended level and above.

Learnability

The province has begun reflecting on and recording its internal practices. This supports a classification at the Disclosed level, which involves informal documentation and initial steps toward process standardization. However, they are not yet systematic, iterative, or supported by centralized tools. The lack of structured organizational learning or public feedback loops prevents progress to the Comprehended level.

Table 16 summarizes the status of transparency efforts in the province of Brabant across the 6 assessed dimensions.

Dimension	Level	Assessment
Accessibility	Disclosed	A pilot of public sensor registry and inventory for internal use exist. Future public transparency efforts are planned but not yet realized.
Usability	Disclosed	Public-facing usability remains limited to basic search functionality.
Informativeness	Disclosed	Basic information model exists but technical language dominates.
Understandability	Opaque	Public-oriented explanation strategies are minimal so far.
Auditability	Disclosed	Internal mechanisms exist to track sensors deployed by the provincial government, but citizen auditability is absent.
Learnability	Disclosed	Some early steps were made to document disclosure processes.

Table 16: A Summary of the Province of Brabant Assessment

6 Discussion

6.1 The Design Choices of the IoT-TMM

The IoT Transparency Maturity Model (IoT-TMM), developed as the core artifact of this study, serves not merely as a conceptual framework but as an instrument to support municipalities in navigating the complex and evolving demands of transparency in people-centered smart cities. Its layered structure is informed and inspired by a synthesis of conceptual foundations—particularly the transparency qualities outlined by Cappelli et al. (2013), the iterative, user-oriented, and data-driven transparency cycle proposed by Matheus et al. (2021), practice-oriented BOLD framework by Matheus and Janssen (2015), and the Window Theory by Matheus and Janssen (2020). Additionally, it draws upon Arnstein's (1969) ladder of participation to situate transparency within broader civic engagement processes. In doing so, the model conceptualizes transparency not as a static, technical end-state, but as a staged, context-sensitive, and socially embedded process.

To achieve this vision, the model combines the Goal-Question-Operationalization (GQO) method with the McKinsey 7S model, enabling a granular mapping of transparency practices across both technical systems and organizational structures. This dual-layered approach ensures these practices are embedded into the 7 dimensions required for sustainable organizational change (discussed in detail in section 6.2). Additionally, the model introduces key novel extensions. These include a people-centered logic grounded in user needs, the integration of Learnability as a dimension to support both institutional expansion and inter-municipal replication, and a deliberate commitment to technology neutrality—ensuring that transparency can be advanced regardless of a municipality's technical infrastructure.

The *first and most significant* design contribution lies in the model's explicit people-centeredness orientation, achieved through its alignment with the Data-Driven Transparency cycle from Matheus et al. (2021). The model explicitly begins with the "eliciting data needs" phase, ensuring that the transparency progression is grounded in the real concerns and interpretive capacities of the public. This design choice was reinforced during expert interviews, where practitioners emphasized the need for transparency to resonate with the lived experiences and preferred modalities of residents; as one participant noted:

> "*It is necessary to enter into a discussion with residents about their needs and wants, both the content and the form in which the information is made available*".

This design choice reflects a broader shift away from the treatment of transparency as a check-list compliance task and toward the development of transparency as a dynamic capability—one that supports "sensing" public needs, "seizing" opportunities for engagement and enhancing awareness, and "transforming" internal practices accordingly (Teece, 2016). Accordingly, dimensions such as Understandability and Informativeness were refined to encompass "sensing" support mechanisms, including signage posts, literacy campaigns, public learning, as well as developing mental models and tech intuition, (Jimerson, 2014; Sander, 2024).

A *second* novelty of the IoT-TMM is the integration of *Learnability*. This addition directly addresses long-standing concerns in the literature and empirical interviews that smart cities initiatives, including transparency, often remain confined to pilot projects, constrained by time-limited funding, siloed implementation, and a lack of mechanisms for institutional memory and adaptation (Bundgaard & Borrás, 2021). The IoT-TMM extends its scope by embedding Learnability as a capacity that reflects a municipality's ability to document, reflect on, update, and transfer transparency practices over time. Learnability is conceptualized as the organizational capability to institutionalize transparency through developing internal knowledge repositories, cross-departmental learning routines, iterative processes improvement, and partnerships that allow successful practices to be either expanded within the organization or replicated across organizations. This responds to the dual trajectory of scalability articulated by van Winden and van den Buuse (2017): *expansion*, referring to the deepening and institutionalization of practices within a single organization, and *replication*, which denotes their adaptation and transfer to new jurisdictions or contexts. "*We're starting over again*" said one respondent, "*One product owner is going department by department asking: where are your sensors?*". Another respondent noted "*Some colleagues didn't even know what a sensor really was*". This reveals foundational knowledge gaps within administrations themselves and highlights the urgent need for formalized learning systems that support continuity and scalability. By positioning Learnability as a critical dimension, the IoT-TMM enables institutionalization of transparency by reinforcing learning infrastructures. This design element responds to long-standing critiques that smart city pilots remain unscalable and unrepeatable due to a lack of structured reflection and learning infrastructure (Matta et al., 2025).

A *third* distinguishing feature of the IoT-TMM is its commitment to technology neutrality. The model deliberately avoids prescribing specific technology implementation for transparency registries. This design choice ensures that municipalities are free to pursue solutions that align with their institutional capabilities and strategic goals. Larger cities with internal development teams and greater budgets may opt to develop and embed sensor registries directly into their own websites or digital platforms. Conversely, smaller municipalities—such as the province of Brabant—may choose Software-as-a-Service (SaaS) solutions such as the WeCity platform, which offer a ready-made, lower-cost alternative with standardized features. The maturity model therefore serves as a strategic roadmap rather than a technological prescription, guiding transparency development while allowing each municipality to select appropriate technical pathways. By decoupling the maturity framework from any single technical solution, the model avoids creating barriers to adoption and empowers municipalities to innovate within their means. This design ensures the model's applicability across a wide range of municipalities, regardless of size or digital capacity. This flexibility enhances the model's inclusiveness, allowing municipalities to scale transparency initiatives without incurring disproportionate technological or financial burdens (Alfadhli et al., 2025; Grimmelikhuijsen & Welch, 2012).

An equally significant *fourth* design decision underpinning the IoT-TMM is its reliance on self-assessment as a mechanism for both reflection and operationalization. Rooted in maturity model traditions (Becker et al., 2009; Warnecke et al., 2019), this approach empowers municipalities to evaluate their own transparency practices against structured dimensions and maturity levels. By enabling internal learning, gap identification, and iterative goal setting, the self-assessment structure aligns with the broader objective of institutionalizing transparency. It also promotes localized interpretation, allowing each city to tailor the model to its specific governance, technological, and cultural context.

Taken together, these elements—the people-centered logic grounded in public needs, the emphasis on organizational learning through Learnability, the technological neutrality, and the self-assessment foundation—position the IoT-TMM as an instrument not merely for compliance; but to provide a framework for cultivating transparency as a "dynamic capability"—responsive to both societal expectations and the evolving realities of smart city governance (Teece, 2016).

6.2 Toward Institutionalization

A persistent challenge in transparency initiatives, particularly within the context of smart cities, is the difficulty of institutionalizing and scaling practices beyond isolated pilot projects. Many efforts remain project-based, time-limited, and heavily reliant on individual leadership or short-term funding, which undermines their long-term scalability (Bundgaard & Borrás, 2021; Matta et al., 2025; van Winden & van den Buuse, 2017). As one expert put it:

> *"I think one of the issues.. one of the challenges in innovation projects when you have to go from pilot to scaling is who owns it, where does it sit?".*

To address this gap, the IoT-TMM is explicitly designed to support the institutional embedding and the scaling by expansion of transparency practices within municipalities routine (Matta et al., 2025). Each maturity level introduces not only technical and communicative practices but also governance roles, feedback, and knowledge-sharing practices to reinforce organizational learning over time (Matta et al., 2025).

Additionally, the IoT-TMM supports this institutionalization by integrating the McKinsey 7S framework into its operationalized practices. This allows transparency to be embedded across seven interdependent organizational dimensions—Strategy, Structure, Systems, Staff, Skills, Style, and Shared Values—ensuring a holistic approach (Kocaoğlu & Demir, 2019; Kumar & Geetika, 2019; Suwanda & Nugroho, 2022).

Systems— refers to both formal and informal processes that support transparency, such as defined processes and procedures, portals, sensor registries, communication tools, and feedback mechanisms —were the most frequently identified enablers (appearing in 29 practices). This underscores the central role of process management and digital tools as critical instruments for institutionalizing transparency in people-centred smart cities.

Following, *Skills* (11 practices) —reflect core organizational competencies, such as legal literacy, data stewardship, and communication practices, supported through training and expert involvement, and *Style* (9 practices) —captures leadership behavior and organizational culture, particularly the degree of openness, innovation, and commitment to transparency, were the next most prevalent factors, indicating the importance of individual and organizational capabilities, as well as leadership and engagement styles that foster user-centered design and citizen participation. For example, the inclusion of training programs, co-design labs, public signage campaigns, and participatory feedback mechanisms highlight the value placed on how municipalities can cultivate both technical skills and participatory culture.

Moderately represented were *Structure* (8 practices), *Shared Values* (8 practices), *Strategy* (6 practices), and *Staff* (4 practices), which play critical roles in supporting transparency. Structure concerns how responsibilities and authority for transparency are distributed and coordinated across departments. Shared Values—such as openness, trust, continuous improvement, and accountability—form the normative foundation guiding transparency initiatives. Strategy refers to the city's roadmap for progressing through maturity levels, involving regular assessments and gap analysis. Staff refers to the recruitment, training, and development of personnel involved in implementing transparency. The lower frequency does not indicate less importance. Instead, these elements typically emerge early in the life cycle of transparency initiatives—such as during strategic planning—and often remain stable throughout the implementation process. For example, once a municipality commits to principles of openness or designates responsibility structures, these tend to guide the project persistently. Therefore, their foundational role makes them less likely to be referenced repeatedly in the identified practices, despite their underlying influence.

Overall, the findings suggest that while procedural and technological systems provide the backbone for transparency implementation, a truly people-centred approach requires balanced attention to organizational culture, human capabilities, and institutional structure.

6.3 Reflections on the Results

The preliminary assessment of Amsterdam, The Hague, and the province of Brabant reveals distinct patterns and disparities in the maturity of transparency practices. Although each municipality demonstrates a basic commitment to disclosure, their levels of operational transparency, citizen empowerment, and systematic feedback integration vary significantly.

Accessibility emerged as a shared initial achievement across all three municipalities, with each has achieved at least a Disclosed level by making sensor information publicly available, with Amsterdam achieving slightly higher level. However, the findings indicate that accessibility in practice is undermined by low public awareness and limited promotional efforts. Even where registries exist, citizens are often unaware of their presence or unclear about their significance. As one official explained:

> *"The national registry never flew. The complaints we receive don't go through the registry—they go to a general phone number".*

This points to a critical distinction between formal availability and practical accessibility, confirming prior critiques that transparency efforts often stall at the disclosure stage without effectively reaching or engaging the public (Matheus & Janssen, 2020).

Usability follows a similar trend. Although basic navigability is achieved, all three municipalities fall short of offering user-friendly and actively engaging interfaces that encourage interaction. This suggests that technical availability is not enough; genuine transparency requires a user-centred design approach that facilitates easy exploration and feedback, as emphasized by both Lnenicka and Nikiforova (2021) and Matheus et al. (2021).

Informativeness reveals Amsterdam and the province of Brabant are reaching a "Disclosed" level: their registry provides a basic metadata on ownership and purposes. The Hague, however, remain at the Opaque level, offering unstructured and technical data without any structured content.

The dimension of *Understandability*, the ability of the public to engage with and internalize information—presents perhaps the most concerning results. Only Amsterdam is reaching a Comprehended level, through initiatives to improve public literacy and understanding of sensors deployments through signage projects. The Hague and Brabant remain at opaque with no systematic efforts to promote citizen learning. This is a critical gap, as emphasized in the transparency literature by Cappelli et al. (2013) and David et al., (2015), effective transparency depends not only on seeing information but on building the capabilities necessary to understand and act on it (Ananny & Crawford, 2018). This also aligns with what a participant highlighted:

> "*Transparency is only truly successful if residents actually use the information*".

Auditability, on the other hand, represents another major shortfall across all cases. Although the province of Brabant maintains internal assets tracking mechanisms that stores and tracks sensors deployments, none of the municipalities offer robust, public-facing auditability features that allow citizens to verify the accuracy or completeness of sensor registries. The Hague, notably, remains fully opaque in this dimension. This supports the argument that transparency initiatives often prioritize publication over creating mechanisms for accountability, thereby limiting their democratic potential (Matheus & Janssen, 2020).

Finally, *Learnability* —referring to the capacity of municipalities to institutionalize and scale transparency efforts—lags significantly behind other dimensions. Among the three cities, only Amsterdam demonstrates preliminary initiatives aimed at fostering organizational learning and knowledge transfer. These include efforts to document internal practices and participate in a broader inter-city consortium with the goal of promoting shared learning and expanding transparency efforts through collaboration.

To summarize the findings from the three case studies, the table below compares the assessed maturity levels of Amsterdam, The Hague, and the province of Brabant across the six key dimensions of the IoT-TMM.

Dimension	Amsterdam	The Hague	Brabant
Accessibility	Comprehended	Disclosed	Disclosed
Usability	Disclosed	Disclosed	Disclosed
Informativeness	Disclosed	Opaque	Disclosed
Understandability	Comprehended	Opaque	Opaque
Auditability	Disclosed	Opaque	Disclosed
Learnability	Comprehended	Opaque	Disclosed

Table 17: A Comparison of the Case Studies

Overall, findings suggest that municipalities are generally able to reach basic disclosure but struggle to progress into deeper levels of citizen-centred transparency. Amsterdam demonstrates comparatively higher maturity across several dimensions but still reveals significant weaknesses, particularly in auditability and sustained public engagement. The Hague and Brabant illustrate the common pattern where transparency initiatives remain inward-facing—designed more for internal tracking than external empowerment.

This comparative analysis underscores the need for municipalities to rethink transparency not as a one-time technical disclosure, but as a continuous participatory practice, in line with the iterative models proposed by Matheus et al. (2021) and Cappelli et al. (2013). Without deliberate efforts to enhance usability, information clarity, and literacy, transparency initiatives risk reinforcing, rather than dismantling, existing information asymmetries and undermining public trust. Several key themes emerged from the observed results:

- Disclosure in not transparency: While all municipalities had sensor registries, true transparency depends on informativity, understandability, and public engagement. The case studies show that many transparency efforts stagnate at the "Disclosed" level—where information is made available but not yet actionable, understandable, or institutionally embedded. This is aligned with what Fox (2007), Matheus and Janssen (2015), and Ortega-Rodríguez et al. (2020) criticized. Cities need to move beyond compliance-driven approaches and toward transparency that supports public engagement and co-responsibility. However, this must be done with realistic expectations. Transparency should be treated not as a shortcut to trust, but as a supporting condition—especially when paired with participatory governance and institutional integrity.

- The enabling role of dedicated units and staff: The presence of specialized teams for data governance—such as the Responsible Sensing Lab in the Netherlands and Digital

Trust for Public Places in Canada— enabled continuous iteration on transparency initiatives. significantly enabled continuous iteration and innovation in transparency initiatives. These dedicated teams acted as vital knowledge hubs, maintaining continuity and ensuring commitments to evolving transparency practices. As one interview participant noted:

> *"The Responsible Sensing Lab functions as a learning environment. It brings together designers, engineers, academia, and policymaker."*
> — Interview

- Capacity enables, Strategy drives: the case studies revealed that while resources and capacity are important enablers, their effectiveness is amplified by clear strategic intent. Amsterdam benefited from resources, but their effectiveness hinged on coordination, experimentation, and the extensive institutional resources and prior smart city initiatives that demonstrated relatively higher maturity across most dimensions. The Brabant illustrates that even limited resources can achieve progress if there is strategic intent.

- Auditability is a blind spot: A consistent observation across all assessed cases was the lagging maturity in auditability. Despite growing attention to data governance and accountability, basic internal or citizen-facing mechanisms for verifying sensor data, ensuring policy compliance, or allowing public scrutiny of deployments remain largely absent. This represents a critical area for improvement across the board.

The application of the IoT-TMM across three municipalities demonstrated its relevance across organizations of varying institutional sizes, capacities, and governance structures. Notably, the province of Brabant, a relatively small and regionally focused organization, successfully applied the model in its early-stage transparency efforts, indicating that the framework is not limited to large, resource-rich cities (Grimmelikhuijsen & Welch, 2012). In contrast, Amsterdam, as major urban centres with extensive digital infrastructure, offered insights into how the model scales to more complex governance settings. This variation in organizational size and capacity validates the model's flexibility and supports prior calls for configurable maturity models tailored to the needs of different contexts (Patas et al., 2013; Poeppelbuss et al., 2011), which aligns with a key theme emerged from the interviews that transparency initiatives must be adaptive rather than standardized. As one interviewee emphasized: "*Transparency efforts must be adaptive — it's not a one-size-fits-all approach*", pointing to the variation in institutional capacity, digital maturity, and governance structures across municipalities. In response, the IoT-TMM developed in this study was intentionally designed to enable municipalities to interpret and apply the model based on their own strategic priorities, technical infrastructure, and resource availability.

The findings underscore that while municipalities increasingly recognize the importance of transparency, significant gaps persist between ambition and implementation. Even cities with advanced initiatives, such as Amsterdam, struggle with challenges like incomplete sensor registration, limited citizen engagement, and uneven information usability. The research reaffirms that transparency is not achieved through disclosure alone but requires sustained attention to information clarity, understandability, and public empowerment. Furthermore, it highlights the persistent issue of information asymmetry and the risk of transparency paradoxes, where information overload undermines rather than strengthens public trust.

6.4 Practical Implications

Transparency is often embraced as a trust-building tool to regain or maintain public trust in response to public criticism of datafication in smart cities (Porumbescu, 2017). Initiatives such as Amsterdam's Sensor Register or the DTPR framework exemplify efforts to increase public insight, and thus trust, into data practices and smart cities. However, research by Grimmelikhuijsen and Welch (2012) suggest that the relationship between transparency and trust is not linear; Rather, the impact of transparency is shaped by a complex interplay of knowledge and emotion. While transparency may improve understanding of data governance, its overall effect on trust may be limited if people already perceive government as untrustworthy. Pre-existing beliefs about competence, fairness, and alignment with public interest remain far more influential than any standalone transparency initiative. This highlights the need for cities to view transparency not as a cure-all, but as one component in a broader strategy of participation, responsiveness, ethical design, and trust-building mechanisms.

Moreover, privacy concerns are culturally sensitive and can vary significantly across national and cultural contexts (Li et al., 2022; Li, 2022). For instance, individuals from collectivist societies such as China and Korea may hold different expectations around privacy than those in more individualist societies like the U.S (Li et al., 2022). Interestingly, participants in this study acknowledged this variation of attitudes towards privacy among different cultures. Participants confirmed notable cultural differences in privacy attitude in the U.S., while typically characterized as individualist, it showed more collectivist tendencies in relation to their attitude towards privacy concerns; compared to privacy attitudes in Canada and Europe, which consistently emphasized the importance of privacy protections and institutional accountability. This underscores the importance of "sensing" and adapting transparency mechanisms, privacy-related activities, and communications to local values and cultural expectations. Transparency initiatives cannot rely on a one-size-fits-all design. Rather, they must be culturally sensitive, attending to local governance traditions, social norms, and levels of institutional trust.

Furthermore, self-assessment was selected as a practical approach. However, this approach introduces several practical challenges. One key challenge stemmed from the inherent interdependence among certain dimensions, such as informativeness, understandability, and usability, where progress in one often feeds into or reinforces another. This fluid state, where boundaries can appear to overlap, highlights a need for prior orientation for practitioners on how to use the model effectively, clarifying and distinguishing the focus and the subtle distinctions between dimensions, and their interdependencies (see Table 1). Without such guidance, ambiguity in scoring or interpreting maturity levels can arise.

To mitigate these issues, municipalities may benefit from shared interpretive guides, cross-city peer reviews, or the integration of clearly defined assessment model. Such mechanisms would not only promote consistency but also enable benchmarking and shared learning across local contexts. Further discussion of these points can be found in the Limitations and Future Research section (7.2).

7 Conclusion

This thesis, guided by a Design Science Research methodology, set out to develop, validate, and preliminarily apply an IoT Transparency Maturity Model (IoT-TMM) to support municipalities in assessing, operationalizing, and institutionalizing transparency practices for IoT data collection and use in people-centered smart cities. The model aims to move beyond disclosure toward transparency that is meaningful, actionable, and participatory.

To this end, the Goal-Question-Operationalization (GQO) framework was employed to operationalize abstract transparency principles into measurable practices across six dimensions: Accessibility, Usability, Informativeness, Understandability, Auditability, and Learnability. To ensure that these practices could be anchored within municipal operations and governance structures, the McKinsey 7S model was used as a complementary framework to promote institutionalization within broader organizational structures, enabling long-term change.

The model was iteratively refined through expert validation and a preliminary assessment across three Dutch municipalities, demonstrating its practical utility and adaptability across different organizational contexts. Overall, this research affirms that transparency must be understood as a dynamic, ongoing capability—shaped by public needs, informed by organizational learning, and essential to the realization of people-centered smart cities.

7.1 Main contribution

As previously mentioned, the core contribution of this research lies in the development of the IoT Transparency Maturity Model (IoT-TMM), a practice-oriented framework that operationalizes transparency, as an embedded, evolving capability within municipal governance. Building on and extending prior models—such as the outcome-focused maturity model of Cappelli et al. (2013), the user-centered transparency cycle by Matheus et al. (2021), and the BOLD framework by Matheus and Janssen (2015)—the IoT-TMM reconceptualizes transparency as a dynamic capability that must be actively developed, institutionalized, and scaled in response to evolving civic and technological contexts.

Several key features shaped the development of the IoT-TMM:

- People-centeredness: the model begins by engaging with public concerns and integrating citizen perspectives from the outset. This design choice reflects the *sensing* function in dynamic capabilities theory (Teece, 2016), enabling municipalities to detect public expectations and *seize* opportunities to act on these expectations.

- Learnability: Introduced as a novel dimension to support institutional memory and long-term scalability, this dimension addresses knowledge gaps and helps avoid repetition or fragmentation across departments and municipalities. The literature also highlights the role of knowledge management mechanisms in facilitating both the *expansion* and *replication* of effective practices.

- Technology Neutrality: The model is deliberately designed to function across varying technological capacities, enabling both large and small municipalities to engage with it using different technological approaches.

- Self-assessment-based: The model enables municipalities to periodically assess their transparency practices, identify capability gaps, and iteratively improve in alignment with evolving civic, regulatory, and technological contexts, through the use of self-assessment feature—a widely recognized approach in maturity modeling (Becker et al., 2009; Warnecke et al., 2019).

Together, these design elements equip the IoT-TMM to serve not just as a descriptive framework but as a governance instrument that helps municipalities transition from fragmented or pilot-based transparency efforts toward structured, participatory, and scalable practices. The model helps address three persistent challenges, identified in the literature and the empirical interviews: the *institutionalization gap* (the lack of embedded roles, routines, organizational memory for maintaining transparency practices), the *scalability gap* (the difficulty of replicating or transferring successful practices across contexts), and the *engagement gap* (the disconnect between data disclosure and citizen understanding). Its practical application in both large cities and smaller municipalities demonstrates its configurability and strategic value for diverse governance contexts in people-centered smart cities.

7.2 Limitations and Future Research Directions

Several limitations of this study must be acknowledged. *First*, the validation of the IoT-TMM was based on a small number of expert feedback and a preliminary application to three Dutch municipalities. While these cases offered valuable insights, broader empirical testing is necessary to assess the model's robustness, reliability, and generalizability across more diverse governance contexts.

Second, the study is situated within the Netherlands context, a country with relatively advanced digital infrastructure and progressive smart city initiatives. As such, the findings may not directly transfer to municipalities in regions with different institutional capacities, regulatory environments, or levels of digital maturity.

Third, although the model was refined to support transparency initiatives beyond IoT, its initial design remains anchored in the domain of smart city data collection and privacy policies. Additional adjustments may be required to fully adapt the model to other policy areas or sectors, such as mobility, education, or environmental governance, or AI transparency.

Fourth, a key challenge in applying the IoT-TMM to real-world case studies was the transitional nature of many transparency practices. Rather than fitting neatly into a single dimension, several initiatives displayed characteristics that spanned across dimensions and maturity levels, reflecting practices that were still evolving and not yet fully institutionalized. To address this, our assessment followed the bounding definitions provided in Table 1 and Table 4.

Additionally, while self-assessment is well-suited for supporting internal learning and iterative governance improvement (Becker et al., 2009; Warnecke et al., 2019), it introduces some limitations in terms of objectivity. Future research could complement this approach with external assessment or benchmarking frameworks to enhance comparability and validation across cities.

Moreover, this study did not directly include the privacy policies of the digital interfaces through which IoT transparency is often operationalized—such as municipal websites, portals, or mobile applications. These are typically addressed through GUI-based Transparency-Enhancing Technologies (TETs). Nonetheless, the study emphasizes that any implementation of digital interfaces should adhere to both PETs and TETs principles.

Furthermore, while this study lays a foundation for assessing IoT transparency, the IoT-TMM itself can be further enhanced and built upon in future research. Specifically, the Learnability dimension was explicitly informed by both the scalability literature and empirical findings from expert interviews. Nonetheless, its prescriptive capacity in guiding municipalities towards embedding transparency practices could benefit significantly from integrating insights from organizational learning literature, providing a more robust theoretical grounding for its developmental aspects.

Lastly, while this study focuses primarily on ex ante transparency—ensuring that the intended data use is made clear to the public before implementation—it is important to acknowledge that transparency must also extend to ex post processes. This includes mechanisms to monitor the actual use of data and the real-world enforcement of privacy commitments. Technologies such as blockchain have shown potential for enabling immutable, auditable records of data use in IoT systems (Chanson et al., 2019), offering a promising foundation for future extensions of the model. Expanding the IoT-TMM to incorporate ex post transparency mechanisms would help close the auditability loop and ensure a more comprehensive transparency lifecycle.

Several promising avenues for future research emerge from this work. First, a broader application of the IoT-TMM across municipalities—both within and beyond the Netherlands—would provide a stronger empirical foundation and allow for cross-jurisdictional learning. Second, the development of user-friendly digital toolkits or online platforms based on the model could enable easier self-assessment, identify tailored improvement pathways, support the operationalization of transparency goals, and enhance comparability. Third, to better capture the transitional stages, future work could introduce intermediate levels —such as *candidate* or *in-progress*—to acknowledge institutional momentum and intent without prematurely assigning higher maturity. Fourth, the *Learnability* dimension could be further advanced by more explicitly grounding it in organizational learning theory. Such refinements would enhance the model's sensitivity to the evolving nature of transparency practices while maintaining a robust and actionable standard for assessment.

7.3 Final Statement

Transparency remains a vital yet evolving principle in contemporary governance. As public sector institutions increasingly rely on data-driven technologies, the need for structured, citizen-centred transparency grows more pressing. This research contributes to that endeavour by offering a theoretically grounded, practically applicable model that helps bridge the gap between transparency aspirations and operational realities. By continuously refining transparency practices, fostering citizen engagement, and embedding auditability mechanisms, municipalities can move beyond transparency as a symbolic ideal and toward a dynamic, empowering practice that strengthens public trust and democratic resilience.

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9 Appendix

9.1 Declaration 1

I declare the use of AI tools for proofreading and text clarity-enhancing at the final stage. However, the output was revised again using my own style and expressions.

Rania Hakem

June 02, 2025

9.2 Declaration 2

I hereby declare that, to the best of my knowledge and belief, this Master Thesis titled "Transparency as a Dynamic Capability in People-Centered Smart Cities: A Maturity Model from the Netherlands" is my own work. I confirm that each significant contribution to and quotation in this thesis that originates from the work or works of others is indicated by proper use of citation and references.

Rania Hakem

June 02, 2025

9.3 Consent

Name: Hakem Given Name: Rania Student number: 0967505

Course of Study: Public Sector Innovation and E-Governance

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Title of the thesis: Transparency as a Dynamic Capability in People-Centered Smart Cities: A Maturity Model from the Netherlands.

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Rania Hakem

June 02, 2025