Effective urban dashboards for local public administration: taxonomy and recommendations.

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Abstract. Urban dashboards (or city dashboards) have emerged as tools that are able to help both citizens and local policymakers understand the state of a city and act accordingly, to address service disruptions and risks, and seize opportunities. However, at present, urban dashboards remain evolving tools whose effectiveness for local public administration is still largely unknown. The research question supporting the present work addresses the effectiveness and usability of urban dashboards with respect to their various scopes, as well as which features are most important for their effectiveness. To study this topic, the research proposes an analysis framework to investigate the features and critical success factors for effective urban dashboards addressed to the local public management. A selection of 21 urban dashboards was analyzed through this framework, leading to a discussion of key insights and recommendations on how to define and implement a robust, effective, and useful urban dashboard for city governance.

Keywords: Urban dashboard; Performance indicators; City governance; City management; Local public administration; Public sector.

1 Introduction

Urban Dashboards (UDs) can be defined as information technology platforms collecting, processing, and sharing data about a city's state [1]. Such urban dashboards (or city dashboards) have emerged as tools that are able to help both citizens and local policymakers understand the state of a city and to act accordingly, to address service disruptions and risks, and to seize opportunities [2]. The concept of the urban dashboard is quite recent, but it has its roots in earlier dashboards and platforms conceived as infrastructural artefacts and tools designed to collect data in order to support decision-making [3,4].

UDs are increasingly adopted thanks to advances in Information and Communication Technology (ICT) and their potential to help local administrators implement more adaptive, inclusive, and resilient urban policies that enhance citizens' well-being. However, the concept of UD remains broad and loosely defined, encompassing a diverse range of systems and perspectives. Such systems range from IT tools processing real-

time raw data to platforms that manage city performance using Key Performance Indicators (KPIs); from interactive citizen-accessible platforms to restricted systems designed solely for policymakers; from comprehensive dashboards that depict the city as an integrated and complex system, to specialized tools targeting specific issues such as flood prevention or mobility; and so on [5,6].

Urban dashboards are still evolving tools whose effectiveness for local public administrations (PA) is still largely unknown. Both the scientific literature and the professional reports about this topic have largely overlooked the real-world application and practical value of these tools. While some dashboards are conceived as theoretical frameworks, others have been developed as pilot projects or implemented by local governments and agencies – yet few provide evidence or feedback on the factors that actually contribute to their effectiveness [7]. The research question supporting the present work addresses the effectiveness and reliability of urban dashboards for local public administrations, focusing on which features are most critical to their quality and performance.

To explore this issue, the research introduces an analysis framework to identify the key features and critical success factors for effective urban dashboards addressed to local public governance. A sample of 21 urban dashboards was selected and analyzed using this framework, leading to a discussion and a set of conclusions on how to define and implement urban dashboards that are robust, effective, and practically useful for city governance.

The remainder of the paper is structured as follows: Section 2 reviews the literature about urban dashboards; Section 3 describes the research methodology; Section 4 presents the analysis framework; Section 5 examines the 21 selected UDs and proposes a taxonomy; finally, Section 6 offers a set of recommendations to enhance the effectiveness of UDs for local PA and concludes with reflections about research limitations.

2 Urban dashboards: literature review

Urban dashboards (UDs) are IT tools that collect, process, and visualize city-level data to support local policymakers in city management and governance [8]. Given this broad definition, UDs encompass a wide range of diverse systems that share common elements, such as the territorial scope, data visualization, and the application of innovative IT tools. However, a review of scientific literature on UDs, their functionalities, and objectives shows a lack of focused analysis, indicating the need for deeper exploration of the topic [9].

Over ten years of scientific research about urban dashboards, the main studied topics have concerned the informatics aspects of the tools. Processing methods have evolved over time, and data analytics modules are one of the core components of effective urban dashboards, moving from traditional algorithms to Artificial Intelligence (AI) [10,11,12]. UDs are especially focused on visualization techniques and enhancing dashboard interactivity [13,14,15].

Data lie at the core of an urban dashboard, and their collection represents one of the most critical aspects [16]. Most UDs are conceived to collect real-time data and to process them to depict a real-time picture of the city's status in a certain time [17]. Sensors are frequently studied as the hardware component used to collect data in an efficient and effective way [15, 18]. Some UDs rely not on raw data, but on indicators to evaluate city performance; in this case, the main studied topics regard how to measure the indicators, select them appropriately, and integrate them into a cohesive representation of the city's condition [11,19,20,21].

One of the most investigated topics concerns how users interact with the UD and whether this interaction is effective. Several authors argue that the effectiveness of a UD depends not only on the quality of its analytics or on the configuration of visualization techniques, but more importantly, on the alignment between its architecture and users' needs and perspectives [22]. For these reasons, several researchers advocate for a participatory process in the development of UDs, in order to consider the needs, expectations, and skills of end users from the early stages [1,23,24].

An important theme emerging from the literature is the broad and heterogeneous scope of UDs and their diverse target audience. UD users can be generally classified into two main groups: citizens or policymakers and public officials [25]. Citizens are typically seen as recipients of UDs designed to collect large volumes of real-time data, process it, and present it in a fast and simplified way, offering users an immediate and comprehensible view of the city's state, for supporting everyday tasks such as choosing the right bus or finding a parking spot [13,26]. Such UDs should be easy to use and not require technical skills [14].

UDs addressed to policymakers and public officials are often based on long-term data and performance indicators derived from more sophisticated data processing techniques [27]. The primary goal of these tools is to support informed decision-making, aimed at addressing skepticism surrounding the use of IT in policymaking and public administration, as well as the limited adoption of decision-support systems in city governance and management [28].

This literature survey also provides a basis for reflecting on the weaknesses in the implementation of UDs. These weaknesses arise primarily from an overemphasis on technical and IT aspects, often at the expense of alignment with city management processes [29]. Moreover, there is a misalignment between the theoretical frameworks and their empirical application: although urban data architecture is considered essential for effective UDs, the corresponding frameworks are often missing or poorly aligned with actual implementation efforts [6,30]. Even though some studies propose design and development approaches for effective UDs, these approaches are rarely implemented in practice. The effective use of UDs in policymaking and local administration remains largely unexplored, and no established frameworks currently define the best methods or requirements for their effective implementation, leaving many dashboards at risk of underuse or abandonment.

Finally, although a shared and robust definition is still lacking, there is a growing consensus among both scholars and practitioners on the fundamental elements of an urban dashboard: a set of IT tools for processing and visualizing data, information, and results; a large volume of diverse and heterogeneous data describing the state of the

city or specific aspects of its services or characteristics; a defined scope, either broad or narrow, based on the dashboard's intended audience; and a theoretical framework to support data collection and analysis at the city-level [2,3,6].

In summary, the scientific literature has explored numerous technical and theoretical aspects related to urban dashboards, but significant gaps remain. In particular, the implementation and usability of dashboards by local administrations are often overlooked, there is a lack of standardized models, and end users are rarely involved in the design process. Moreover, the relationship between specific design features and the actual effectiveness of these tools in supporting urban governance has not been adequately investigated.

3 Research Methodology

The research methodology builds upon a comprehensive literature review and an in-depth analysis of 21 urban dashboards. This twofold approach aims to identify the current state of the art, highlight the strengths and weaknesses of existing implementations, and outline an Urban Dashboard taxonomy for more effective deployment.

The analysis is structured as follows (see also Figure 1):

1. This paper addresses the following two research questions:
   RQ1: What are the critical design elements and key components that define the architecture, tools, data, and scope of urban dashboards?
   RQ2: What are the critical factors that influence the effectiveness of urban dashboards in supporting public administration and city governance?
2. A set of UDs is selected, based on three criteria for selection: (a) the UD is studied in a scientific paper, or (b) it represents an international best practice, and (c) it is addressed to local managers and policymakers. The selection process ensures that at least one of the first two criteria (a or b) is met, along with the mandatory criterion (c).
3. An analysis framework is developed to evaluate urban dashboards as tools for effective city governance. The core dimensions of this framework are derived from the constitutive elements of an urban dashboard identified through the literature analysis.
4. The framework is applied to the selected UDs. The results are presented in tables and graphs and used to discuss the critical success factors for effective UDs.
5. Applying this classification to case studies allows the identification of strengths and weaknesses of dashboards. Finally, a set of recommendations is proposed to bridge the gap between theoretical frameworks and practical implementation.

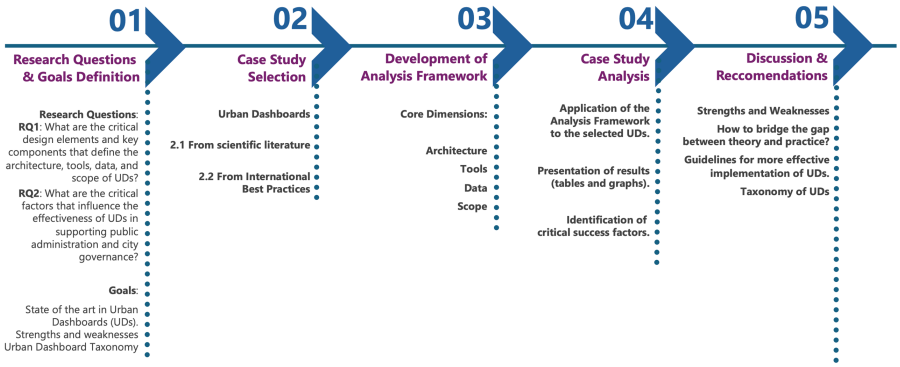

Fig. 1. The methodology workflow (source: Authors)

3.1 The urban dashboard selection from the scientific literature

This section describes the selection of UDs from the scientific literature, aiming to identify dashboards that were fully implemented and actively used by public administrators. Papers were selected based on two criteria: open access availability, to enhance research transparency, and relevance to the study's core focus – city management and governance. Subsequently, the analysis identified papers aligned with the study's objectives. A text analysis showed strong alignment with the research focus in 35 papers that are highly relevant to the research topic. The following step involved identifying urban dashboards described in the selected papers. Only 13 papers provided a detailed description of an implemented urban dashboard. Therefore, these 13 papers constitute the final set of UDs selected from the scientific literature (Table 1).

Table 1. Urban dashboards from the scientific literature survey

n	Title	Source
1	Sustainability in Urban Areas (Thessaloniki, Greece)	[31]
2	London City Dashboard	[32]
3	Dublin Dashboard	[32]
4	Citizen Satisfacton Index (Argentina)	[33]
5	(Centro De Desarrollo Urbano Sustentable) Indicator Set (Urban Sustainability)	[34]
6	Resilience Framework (Fukuoka, Japan)	[35]
7	Criminal Risk Index (Wroclav Poland)	[36]
8	The Cultural City OLS Model	[37]
9	Social Equity of Urban Parks	[38]
10	TOD Index for polycentric City. (TOD. Transit oriented Development)	[21]

11	X Minute City New Zealand 2022	[39]
12	SCS (Soft city sensing Framework) Computational Humanities	[40]
13	Geoinformation System Polonia for Housing Management for Rent (MHS)	[41]

3.2 The urban dashboard selection from the international best practices

The selection of urban dashboards from international best practices aims to include cases developed by internationally authoritative institutions and implemented at the city level by local public administrators but not examined in the scientific literature.

To identify which international institutions can be considered reliable, both for their authoritativeness at the international level and for their consistency with the topics of urban management and governance, the research adopted the OECD's definition of Landscape International Organisations (LIOs) as entities supporting their members to address today's global challenges at the territorial level and to support the achievement of public policy objectives [42]. According to this criterion, the research involves the following LIOs: UN (United nations); OECD (Organisation for Economic Co-operation and Development); UNDP (United Nations Development Programme); the Worldbank; the CDRC (Consumer Data Research Centre), an agency funded by UK Economic and Social Research Council (ESRC); and the Rockefeller Foundation, a U.S. organization supported by public and private funding.

The Analysis of UD reporting involves the examination of institutional reports from selected LIOs to identify UDs whose goals and features align with our topics. This analysis allows for the selection of eight UDs developed by authoritative LIOs, which can be considered international best practices and included in the final set. An exception was made to include a dashboard developed by the non-profit organization Radio Global City Network, selected for the quality and richness of its data and visualization capabilities. The results of the selection are listed in Table 2.

Table 2. Urban dashboard as international best practices

n.	Title	Source
1	Innovation and Data Use in Cities	[42]
2	How's life	[43]
3	Shalom City Index, Radio Global City Network	[44]
4	Index of multiple deprivation	[45]
5	City Resilient Index	[46]
6	Human Development Index	[47]
7	UN Water, Sustainable Development Goals (SDG) Index	[48]
8	Worldbank Urban Population	[49]

4 The analysis framework

To analyze the selected 21 UDs, a dedicated analytical framework was developed, rooted in the scientific literature on the definition and characteristics of UDs. The study of some UD definitions [9,27,50,24] allows the identification of four core dimensions of a UD:

- Architecture: concerns the design process or theoretical framework defining how the UD is built and giving a comprehensive vision to the system.
- Tools: it explores the IT tools aiming at processing and visualizing data.
- Data: examines information collected and processed to feed the dashboard, and subsequently displayed.
- Scope: it focuses on the goals of the UD, considering the perimeter of its analysis and the recipients to whom it is addressed.

All these aspects affect the features and the quality of a UD, conceived as the capability of the tool to respond to the user's needs. Such components are very general and need to be detailed. Therefore, the scientific literature on UDs was examined to identify the most recurrent components of such 4 core dimensions. These components were selected through a two-phase process involving the codification and comparison of keywords emerging from the scientific literature.

With regard to the Architecture, several studies agree that a theoretical framework is essential for designing an effective UD, although many existing dashboards lack this foundational element [2,6,23]. Consequently, the presence – or absence – of a theoretical basis can be regarded as a critical success factor. Similarly, the way an UD is developed and implemented is considered to affect its effectiveness. For instance, if the tool is designed in a top-down manner – without any user involvement – or through a bottom-up, participatory process can significantly influence its success [24,51,52]. User involvement is a key success factor in the implementation of an urban dashboard, especially when a local authority serves as the process owner. A strong partnership with the public entity that will ultimately use the dashboard is also regarded as a critical element for success [32]. Therefore, the analysis of a UD's Architecture can be assessed with reference to 4 components: (1) Theoretical Framework, (2) Top-down model, (3) Bottom-up model, (4) Institution Partnership.

With regard to IT tools, most papers identify two main critical aspects: data processing and data visualization. Data processing refers to how data are handled to provide insights into the city's condition and to support policymaking. One key issue concerns the aggregation model – that is, how data and indicators are calculated and aggregated to depict the city's state [11,53]. Another emerging concern is the breadth of the scope: whether the UD focuses on a single topic or dimension of the city, or addresses multiple dimensions and topics [14,34]. The use of AI, although still uncommon in UDs, represents an additional tool for processing and managing large volumes of urban data [12]. With regard to visualization, the use of graphic tools and geographic maps enhances the effectiveness of UDs [8,16,54,13]. Therefore, the analysis of IT tools in a UD can be conducted across 6 elements: (1) Aggregation Method, (2) One-dimensional, (3) Multidimensional, (4) AI UD, (5) Graphic UD, (6) Geospatial UD.

The quantity and quality of data are also crucial to the effectiveness of a UD [29]. In terms of data quantity, UDs are often theoretically defined, but lack the actual data to populate their datasets; hence, data availability is a critical issue [27]. Open data sources influence not only the quantity, but also the transparency of data [15,18]. Data quality impacts the reliability of a UD: it depends on the transparency and neutrality of the data processing [3,17], as well as the authoritativeness of the data source [50], which should be clearly demonstrated through highlighted data explanations. Therefore, the analysis of the data component of UDs can be conducted with reference to the following 4 aspects: (1) Data availability, (2) Open data, (3) Data highlight, (4) Source authoritativeness.

Finally, the scope of a UD also affects its effectiveness [7,29]. A well-defined scope is essential for guiding data collection, processing, and visualization. As previously mentioned, UDs can be classified according to their intended recipients – either citizens or policymakers. In the first case, citizen engagement is a key success factor for a UD [25,26], in the second case, the presence of a decision-making tool is crucial to support policymakers [5,55]. Moreover, some studies outline that the territorial scope of a UD is another factor influencing its effectiveness [4]. Large cities, in particular, are not homogeneous, but vary significantly across neighborhoods and districts. Therefore, a UD's ability to scale across different territorial levels is a key driver of its effectiveness [28], as is its capacity to support comparisons between multiple cities. Finally, the scope also concerns the temporal depth, that is, the use of historical data [22,54]. Thus, the analysis of the scope of UDs can be carried out with respect to the following 5 aspects: (1) Citizens Engagement, (2) Decision Making, (3) Area Scaling, (4) Benchmarking, (5) Temporal depth.

Table 3 summarizes the four core dimensions and the 19 features that define the UD analysis framework.

Table 3. The UD analysis framework

Core dimensions	Features	Description
ARCHITECTURE	Theoretical Framework	The UD has or not a theoretical framework
	Top-down model	Top-down approach to the framework
	Bottom-up model	Bottom-up approach to the framework
	Institution Partnership	The UD is commissioned and/or funded by an entity or an institution.
TOOLS	Aggregation Method	The aggregation method for create indicators and composite indicators is highlighted
	One-dimensional	The UD displays a reporting activity aimed at a specific city dimension.
	Multidimensional	The UD displays a reporting activity aimed at many city dimensions.
	AI UD	The UD is implemented with the Artificial Intelligence
	Graphic UD	The UD interface is supported by infographics and interactive moving graphics
	Geospatial UD	The UD interface is also supported by interactive maps and geolocated data and/or indicators
DATA	Data availability	The data platform is implemented with available data
	Open data	Data and indicators are available in open access mode
	Data-highlight	Data sources of indicators and descriptors are highlighted
	Source authoritativeness	The data sources, when declared, are authoritative
SCOPE	Citizen Engagement	The dashboard is a tool for engaging citizens

	Decision Making	The dashboard is a tool for supporting policymakers in the city governance
	Area Scaling	The use of different dimensional scale to compare intra-urban and inter-urban performances (temporal depth).
	Benchmarking	The UD allows a comparison between cities or regions.
	Temporal Depth	The dataset includes historical series of data that allows to monitor the city trends (spatial depth).

5 Results and discussion

The analysis of the 21 selected urban dashboards, listed in Table 1 and 2, is conducted using the analytical framework described in Table 3. The complete analysis framework is illustrated in Figure 2.

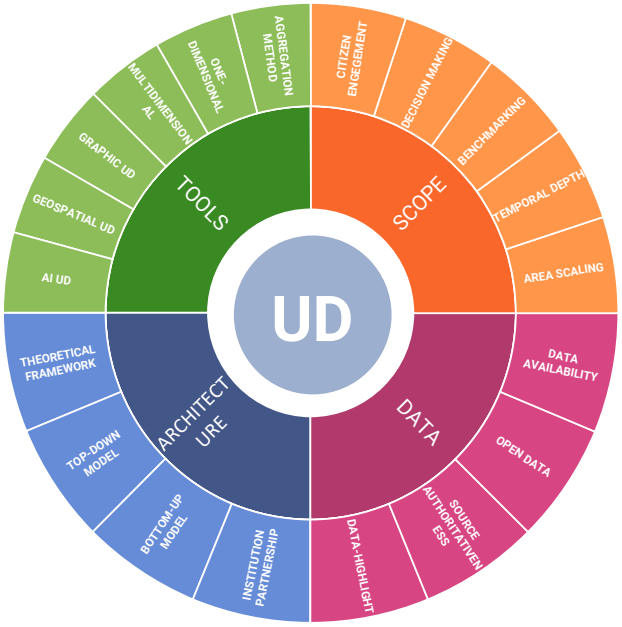

Fig. 2. The UDs analysis framework (source: Authors)

Each of the 21 UDs is evaluated by applying the analysis framework and the 19 features, using a binary scoring system: 0 indicates the absence of a specific feature, and 1 indicates its presence. Attachment 1 presents the scoring: row totals indicate the number of features present in each UD, while column totals indicate how many UDs are characterized by a specific feature.

To answer RQ1, this study compares the UDs with one another and identifies their features. The analysis results are commented in Section 5.1 with respect to the four core dimensions. Then, to answer RQ2, Section 5.2 discusses the implementation approaches and best practices to highlight the strengths and weaknesses of these tools.

5.1 Critical Design Elements and Key Components

The first core dimension concerns the architecture of the UD, as shown in Figure 3.

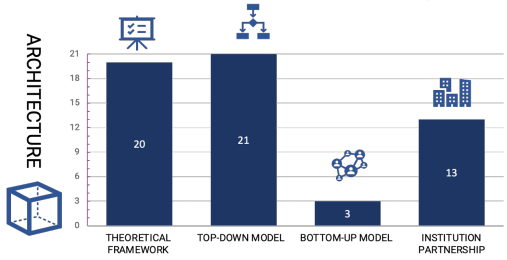

Fig. 3. Results of the first dimension: Architecture (source: Authors).

Nearly all UDs (20 out of 21) are based on a THEORETICAL FRAMEWORK, which provides a solid theoretical basis and a strategic vision for the dashboard. In terms of implementation approach, the TOP-DOWN MODEL prevails. Although all 21 UDs adopt a top-down approach, three also incorporate bottom-up elements, suggesting the emergence of a hybrid model, highlighting the potential for value co-creation and participatory design, even in UD's with a strong top-down orientation. Another important factor is the role of institutional partnerships – primarily involving local authorities – in both the design and funding of dashboards, with 13 out of the 21 UDs demonstrating such collaborations.

IT tools refer to how the dashboard functions in terms of data processing and visualization; the analysis results are shown in Figure 4.

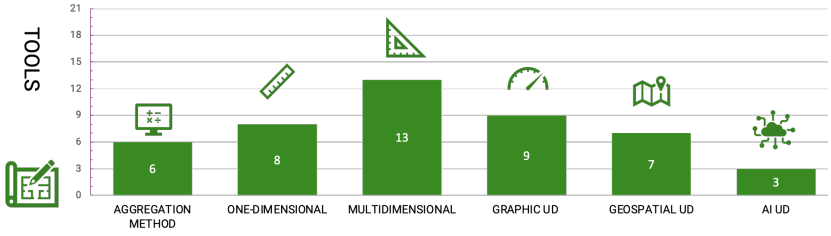

Fig. 4. Results of the second dimension: Tools (source: Authors).

The AGGREGATION METHOD used to calculate indicators is not always specified within the 21 selected scientific papers and institutional reports: only 6 of the examined UDs provide a description of their data aggregation model. The complexity of the user interface tends to correspond with the thematic breadth of the dashboard: 8 of the case studies focus on a single topic – for instance circularity, or mobility (ONE-DIMENSIONAL) – while the majority, 13 UDs, address multiple topics simultaneously (MULTI-DIMENSIONAL). The visual tools supporting the processed data range from the most traditional visualization models, represented by GRAPHIC UDS (9 cases), to GEOSPATIAL UD, where data and indicators are displayed through georeferenced maps

(7 cases). The most complex and innovative models are AI-INTEGRATED UDS, which currently form a minority, appearing in only 3 cases.

Data are a core resource for UDs, and their selection, availability, and quality are critical success factors. Figure 5 shows the score for the components of this dimension. The figure illustrates the effectiveness of UDs based on the reliability of the data: their availability, which supports the functioning; the presence of open data, which affects the transparency, especially when the data are highlighted; the authoritativeness of the data source, which enhances the robustness of the dataset.

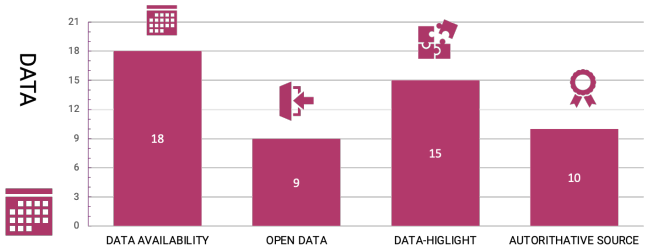

Fig. 5. Results of the third dimension: Data (source: Authors).

18 of the examined UDs demonstrate good DATA AVAILABILITY, meaning that the UD was implemented using available data. 9 of the UDs use OPEN DATA, ensuring a better ability to analyze the data that make up the framework, as they are freely accessible. 15 UDs HIGHLIGHT DATA, meaning they make available the list of selected data or indicators, and only 10 declare the use of AUTHORITATIVE SOURCES (public and/or institutional).

The goals and intended recipients of each UD represent a critical dimension of analysis. Figure 6 shows the analysis results for this dimension.

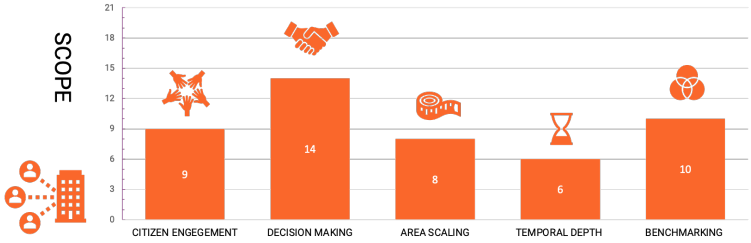

Fig. 6. Results of the fourth dimension: Scope (source: Authors)

Regarding the scope, 9 UDs are also aimed at communities with CITIZENS ENGAGEMENT objectives. 14 dashboards are addressed to decision makers, highlighting that UDs are considered highly technical tools. A relatively low number of UDs provide in-depth features for comparison and measurement trough AREA SCALING (8 items), TEMPORAL DEPTH (6 items) or benchmarking between cities (10 items). These elements enable comparisons among different cities and regions, as well as among various parts within the same city.

In summary, a synoptic view of the 18 indicators revels that some components emerge as common features of most UDs: the THEORETICAL FRAMEWORK, the TOP-DOWN MODEL, a good DATA AVAILABILITY, which indicates effectiveness in the tool implementation. There are also several trends involving a significant number of dashboards: the presence of INSTITUTIONAL PARTNERSHIPS in the design process; DECISION-MAKERS as main recipients; the declaration of AUTHORITATIVE SOURCES; and the implementation of MULTI-DIMENSIONAL dashboards.

However, some critical points also emerge. CITIZENS ENGAGEMENT is limited, both in terms of target users and during the project development phases – as participatory processes are almost always absent. Many dashboards also lack AREA SCALING and TEMPORAL DEPTH. Furthermore, very few dashboards currently use Artificial Intelligence algorithms as tools for data analysis and comparison (see Attachment 1).

5.2 Implementation and best practices

The aim of this study is to assess the quality and the relevance of urban dashboards for their users, deepening their effectiveness as decision support tools for local public administrations.

To answer RQ2, regarding the effectiveness of UDs as decision support tools for local public administrations – in terms of key features – the authors analyzed 21 UDs using the analytical framework developed for this purpose. Building on the Core dimensions identified (Architecture, Tools, Data, Scope), this section discusses and highlights the strengths and weaknesses identified across the 19 features of the dashboards. The discussion focuses on the design process, data quality, and informational effectiveness.

With respect to the design process, the literature survey identifies two main aspects affecting UD effectiveness: the theoretical framework and the involvement of end-users. The research reveals that 20 out of 21 UDs are designed in accordance with a THEORETICAL FRAMEWORK. On the contrary, the BOTTOM-UP approach, which involves citizen participation, is adopted by only 3 UDs (Figure 7). This highlights a gap between recommendations in the scientific literature and current implementation practices.

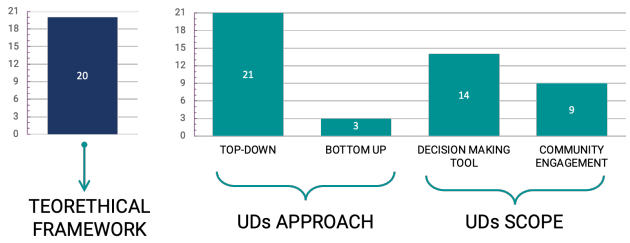

Fig. 7. Design components (source: Authors).

A comparison between the UD design approach and the UD scope, reveals that designers of UDs as decision making tools prefer a TOP-DOWN approach – grounded in

expert led implementation through a theoretical framework – over a bottom-up approach that involves citizen participation and is often perceived as less reliable. However, some cases (9 out of 21) demonstrate that it is possible to reconcile the use of a theoretical framework with community co-creation processes [56]. Although several authors recommend co-creation, none provide concrete methodologies for involving citizens; consequently, this recommendation remains largely unimplemented in practice, as demonstrated by empirical investigations [1,22,23,24].

Data quality concerns certain features of data processed by the UD and the way they are processed, as described in Figure 8.

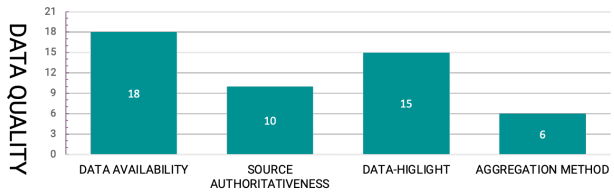

Fig. 8. Data quality (source: Authors).

Data quality is a key determinant of the robustness and reliability of the dashboard. It depends on DATA AVAILABILITY, data SOURCES' AUTHORITATIVENESS, data highlight, and the clarity of the data AGGREGATION METHODS. The first aspect concerns data availability: dashboards should be populated with comprehensive datasets, rather than left as unpopulated frameworks. In the survey, 18 out of 21 dashboards are populated with real data. This high number is justified by the selection criteria, as only implemented UDs were included in the study, excluding those that were designed but not yet implemented. Data should be reliable, and the quality of the data source – specifically its authoritativeness – serves as a proxy of data reliability. However, only 10 UDs explicitly indicate the authoritativeness of their sources. In many cases, the origin of the data is unknown, which significantly undermines the reliability of the dashboards. Explanations of what the data represent and how they are processed to compose indicators (what we call DATA HIGHLIGHT) are often missing. This lack of clarity regarding aggregation methods compromises the overall transparency of the UD. Empirical investigation confirms [20] that data and indicators are often selected without a strong link to their practical use in supporting urban decision-making. The lack of disclosure regarding data processing or retrieval reduces confidence in the effectiveness of UDs.

The quality of a UD also depends on its ability to produce useful information and knowledge about the state of the city. There are three components that provide UDs with analytical depth for comparisons over time, across space, and among citizens, as reported in Figure 9.

The first component is TEMPORAL DEPTH. Historical datasets are more valuable, as they support the interpretation of urban phenomena by enabling "before-and-after" analyzes, allowing for the assessment of growth (or decline) of the qualitative levels related to the urban themes examined by the UDs. Furthermore, the presence of historical

data series enables the development of forecast scenarios, thereby supporting policy-makers. Despite this, dashboards with temporal depth are still rare – only 6 currently include it.

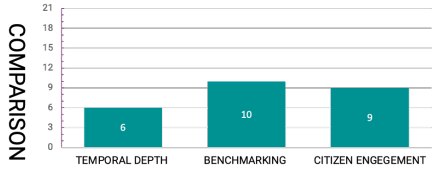

Fig. 9. Data components of UDs (Source: Authors).

The second component is spatial comparison, that is, BENCHMARKING between cities or regions with similar characteristics. This enables dashboards to foster dynamic, cross-cutting comparisons across different issues, rather than simply generating rankings. Only 10 out of 21 UDs allow benchmarking.

Another gap between the scientific literature and empirical practice concerns citizens engagement. While the scientific literature emphasizes the active role of citizenship as a key recipient of dashboards, practical implementation often fails to reflect this perspective. The majority of dashboards are instead primarily targeted at managers and politicians.

A further consideration regarding richness and relevance of a UD involves the topics it faces (Figure 10).

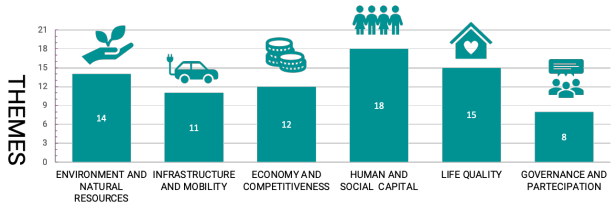

Fig. 10. Themes (source: Authors).

About one-third of the case studies focus on a single topic, such as circularity, or mobility, or similar one-dimensional dashboards. However, the majority of UDs appear as multi-dimensional dashboard, addressing many topics simultaneously. In this regard, an in-depth analysis identifies 6 key topics commonly covered by the UDs, aligned with the thematic areas of Giffinger's smart city framework: Environment and natural resources, Mobility and infrastructures, Economy and competitiveness, Social and human capital, Quality of life, Governance and participation. Applying these themes to the 21 UDs, a strong interest emerges in topics related to people and the human capital, as well as quality of life. Other relevant themes include the environment and its relationship with urban and natural resources; the economy and city competitiveness, and issues surrounding infrastructure and mobility. In contrast, governance

and participation are the least represented. Overall, the broader the range of themes addressed by a UD, the greater is its relevance.

5.3 Discussion

The literature analysis reveals a wide range of topics related to the design and implementation of urban dashboards. However, very few – if any – studies address the effective adoption and use of UDs by local public managers and politicians [7, 15]. At present, urban dashboards often appear more as theoretical concepts than a concrete artifacts. An examination of both scientific papers and institutional reports shows that many well-designed dashboards have never been implemented in practice. Nevertheless, the scientific literature provides a valuable foundation for identifying the core dimensions and key components of urban dashboards, as well as for critically reflecting on how to design them effectively [1, 2, 54].

The literature survey provides valuable insight into the state-of-the-art of the research on this topic. Many papers focus on theoretical aspects – such as urban framework models, strategic tools, indicator selection and data aggregation methodology [31,34,38], rather than on the practical implementation of urban dashboards. In some cases [32,33,40], urban dashboards are clearly described and analyzed, but they have either not been developed, are no longer operational, or are not available in open access mode. These cases fall short of the goals of the present work and highlight that the current state of the art of urban dashboards remains underdeveloped and largely confined to theoretical design [59].

The literature highlights that some of the most crucial aspects affecting the quality of a UD are primarily found in how it is conceived and designed. Grounding the design of a UD in a theoretical framework is essential to provide it with the structure and robustness needed to address the complexity of the city in an integrated and strategic manner [43]. It also emerges that an urban dashboard is a socio-technical artifact whose effectiveness depends on the involvement of the recipients in its design [58].

A comparison between theoretical principles and the empirical analysis of 21 UDs reveals that, while a theoretical framework is almost always adopted, user involvement – and especially that of citizens – is notably rare [32, 33]. As outlined by several scholars, a misalignment between the functionalities of the UD and the needs, interests, and competencies of its recipients is a probable cause of ineffectiveness or eventual disuse. Nevertheless, to date, there is a lack of empirical studies examining the actual usage of these UDs, which makes it difficult to substantiate such claims.

The present work also investigates another mismatch, between the theoretical and the actual quality of the data used in the UD processing. Despite the literature emphasizing the importance of feeding UDs with reliable and robust data – collected from authoritative sources and spanning broad temporal and spatial dimensions – few case studies adhere to these recommendations [42, 43]. In several cases, it is unclear where the data originate or how the indicators and data aggregations have been constructed, undermining confidence in the tool. Since UDs are relatively new and complex instruments, gaining users' trust is crucial for their adoption in decision-making processes. However, even in this case, there is no clear evidence of a relationship between data

quality and the effective use of dashboards, so definitive conclusions cannot be drawn on this point.

Examining some papers regarding the design methodology of urban dashboards [57, 58, 3], the central role of KPIs and their connection with local policies emerges in making UD effective as a decision-making support. However, even in works that propose field experiments, the analysis of the actual usefulness of the indicators for political decisions is not carried out.

Kourtit and Nijkamp [57] developed a UD for the city of Stockholm, based mainly on benchmarking with other European cities and on the connection between KPIs and urban themes represented by the Pentagon model which defines the 5 critical success factors for cities. However, their work examines how to build the prototype, but does not carry out any verification of its actual use or of the concrete usefulness of UD for making better decisions.

Islam and Suflan [58] start their research from a comparison of some UDs for the cities of Lyon, München, and Wien; the paper experiments with AI algorithms chosen from time to time to address different urban issues, but even in this case it does not carry out a validation with respect to the actual functionality of the developed tools, to understand whether the choice of indicators is aligned with the needs of policymakers.

Nidam et al. [59] experiment with the co-creation of a UD in Massachusetts; users acted as interlocutors and co-creators of the UD, identified information needs and, consequently, the data and indicators needed to implement the UD. In this case, the UD was actually used by citizens, who also conducted an evaluation and iterative design, gradually making any necessary improvements. However, the UD was not aimed at policymakers, and the case study cannot be used to identify a methodology for UDs aimed at public administrations.

Moreover, the literature tends to overlook the relationship between dashboard functionalities and dashboard adoption. Functionalities determine the relevance of the information processed and visualized by the UD for its users. This aspect emerges from the empirical analysis, albeit in a limited number of cases [32, 34]. The ability of UDs to process historical data – and thereby support the analysis of a city's evolution, enable comparisons between cities, or scale down the analysis to the infra-city level (at the neighborhood level) – is crucial for informed decision making and for ensuring that dashboards are perceived as truly useful [47, 48, 49].

6 Conclusions, limitations and further works

Urban dashboards are IT-based tools that process large volumes of data to provide information about the city's state and to support decision-making by local public administrators. These tools have grown in number and use over the past ten years, mainly due to advancements in IT systems capable of processing and visualizing such data and information. Despite the considerable number of papers and reports describing urban dashboards, there is still a lack of a theoretical framework that defines a shared structure and content to ensure their quality and effectiveness.

This study addresses the research question concerning the effectiveness and usefulness of existing urban dashboards by highlighting their components, strengths and weaknesses, as well as the discrepancies between their theoretical features and empirical implementation. Examining 21 concrete cases of implemented UDs, this study shows that that the state of progress in UD design is very advanced. However, the cases of actual use are still limited, and above all, studies validating the effectiveness of UDs for decision makers are largely absent.

The difficulty in verifying the actual use of UD by policymakers stems from barriers researchers often face when interacting with these actors. Furthermore, as can be seen from the literature examined, there is still slow progress toward evidence-based policymaking models. Research should therefore shift from the primarily technological aspects of UDs to the behavior of policymakers. Instead, the analysis of the 21 UDs reveals that the focus has been heavily on the IT aspects of UDs; this trend will continue in the future, given the strong scientific interest in using AI technologies in UDs. A persistent gap therefore remains between technological and political dimensions, which has characterized research on the topic of UDs to date.

This work has some limitations: first, the number of cases examined is limited. A more thorough search of both the scientific literature and urban applications could expand the set of UDs examined and provide a broader and more up-to-date overview. Furthermore, the paper defines a theoretical framework for the analysis of UDs that would require field validation. For this reason, this work is currently under continuous development, mainly through two distinct activities.

The first research activity concerns an improvement of the analysis framework that incorporates not only the study of the critical success factors of the UDs from a functional perspective, but also the critical success factors linked to their adoption and use by the local PA. The authors are supplementing this research by using expert panels and semi-structured interviews.

The second research activity concerns the alignment between the technical functions of UDs and their use by policymakers. This activity is conducted through living labs with politicians and technical staff from local public administrations and aims to create an interactive and iterative design process in which the findings emerging from the living lab lead to improvements and modifications to UDs in line with user needs.

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Attachment 1

	TOOL	STRUCTURE					TOOLS								SCOPE						DATA							
		TOP DOWN MODEL	BOTTOM UP MODEL	COOPERATION WITH INSTITUTIONS	CITY BENCHMARKING	SCALABILITY	FRAMEWORK	INDEX (REPORT)	MULTIDIMENSIONAL INDEX (REPORT)	VISUAL DASHBOARD	GEO - MAP DASHBOARD	DECISION MAKING TOOL	COMMUNITY ENGAGEMENT	USE OF ARTIFICIAL INTELLIGENCE	ENVIRONMENT (NATURAL RESOURCES)	MOBILITY (TRANSPORT AND ICT) mode, Mobility + Infrastructures	ECONOMY (COMPETITIVENESS)	PEOPLE (SOCIAL AND HUMAN CAPITAL)	LIVING (QUALITY OF LIFE)	GOVERNANCE (PARTECIPATION)	DATA SOURCE SHARING	USE OF OPEN DATA	NDICATOR AGGREGATION METHOD	SOURCES QUALITY	SOURCES NEUTRALITY	HISTORIC DATA	DATASET POPULATION (*)	VALUE
1	OECD Innovation and Data Use in Cities	1	0	1	1	0	1	0	1	0	O	0	0	0	0	0	1	1	1	1	1	0	1	1	1	0	1	14
2	OECD How's Life?	1	0	1	1	0	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	0	0	1	1	0	1	18
3	Sustainability in Urban Areas (Tessaloniki, Grece)	1	0	1	1	0	1	1	1	0	0	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	1	14
4	Shalom City Index	1	0	1	1	0	1	0	1	1	0	1	0	0	0	0	1	1	1	0	1	0	1	1	1	1	1	16
5	City Resilient Index	1	0	1	1	0	1	0	1	0	0	1	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0	13
6	Framework For Resilience (Fukyuoka, Japan)	1	0	1	0	0	1	1	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1	8
7	Criminal Risk Index (Wroclav Poland)	1	0	0	0	1	1	1	0	0	1	1	0	0	0	1	0	1	1	0	1	1	1	0	0	0	1	13
8	The Cultural City OLS Model	1	0	0	0	0	1	1	0	0	0	0	0	0	1	0	1	0	1	0	1	1	1	1	1	0	1	12
9	Social Equity of Urban Parks	1	0	0	0	1	1	1	0	0	0	0	0	0	1	1	0	1	0	0	1	1	1	0	0	0	1	11
10	TOD Index for polycentric City. (TOD. Transit oriented Development)	1	0	0	0	0	1	0	1	0	0	1	1	0	1	0	1	1	0	1	1	0	1	1	1	0	1	14
11	Citizen Satisfacton Index (Argentina)	1	1	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	1	1	1	0	0	0	0	0	1	10
12	X Minute City New Zealand 2022	1	0	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0	0	1	15
13	CEDEUS i(Centro De Desarrollo Urbano Sustentable) Indicator Set (Urban Sustainability)	1	0	0	1	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	1	16
14	SCS (Soft city sensng Framework) Computational Humanities	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	6
15	Geoinformatio n System Polonia for Housing Management for rent (MHS)	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	6
16	Index of multple deprivation Consumer Data Researc Center	1	0	1	1	1	1	0	1	1	1	1	0	0	1	1	1	1	1	0	1	1	0	1	1	1	1	20
17	Human Development Index	1	0	1	0	0	1	0	1	1	0	1	0	0	0	0	1	1	1	0	1	1	0	1	1	1	1	15
18	UN Water, SDG's Index	1	0	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	1	1	1	1	0	1	1	1	1	22
19	Worldbank Urban Population	1	0	1	1	0	0	1	0	1	0	1	1	0	0	0	0	1	0	0	1	1	0	1	1	1	1	14
20	LONDON CITY DASHBOARD	1	0	1	0	0	1	0	1	1	0	1	1	0	1	1	0	0	0	0	0	1	0	0	0	0	1	11
21	DUBLIN DASHBOARD	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	1	21
	TOTAL	21	3	13	10	8	20	7	13	9	7	14	9	3	14	11	12	18	15	8	15	9	6	10	10	6	18	
	LEGENDA	0=NO	1=SI																									