TU WIEN Informatics

Developing a Research, Technology, and Innovation Dashboard for Policy Evaluation in the Public Sector

DIPLOMA THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieur

in

Business Informatics

by

Irfan Kacapor, BSc
Registration Number 12124537

to the Faculty of Informatics

at the TU Wien

Advisor: Prof. Christian Huemer

Vienna, September 16, 2025

Irfan Kacapor | Christian Huemer

Erklärung zur Verfassung der Arbeit

Irfan Kacapor, BSc

Hiermit erkläre ich, dass ich diese Arbeit selbständig verfasst habe, dass ich die verwendeten Quellen und Hilfsmittel vollständig angegeben habe und dass ich die Stellen der Arbeit – einschließlich Tabellen, Karten und Abbildungen –, die anderen Werken oder dem Internet im Wortlaut oder dem Sinn nach entnommen sind, auf jeden Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht habe.
Ich erkläre weiters, dass ich mich generativer KI-Tools lediglich als Hilfsmittel bedient habe und in der vorliegenden Arbeit mein gestalterischer Einfluss überwiegt. Im Anhang „Übersicht verwendeter Hilfsmittel" habe ich alle generativen KI-Tools gelistet, die verwendet wurden, und angegeben, wo und wie sie verwendet wurden. Für Textpassagen, die ohne substantielle Änderungen übernommen wurden, haben ich jeweils die von mir formulierten Eingaben (Prompts) und die verwendete IT- Anwendung mit ihrem Produktnamen und Versionsnummer/Datum angegeben.

Wien, 16. September 2025

Irfan Kacapor

Abstract

Dashboards have become central tools for supporting evidence-based policy evaluation, particularly in the public sector where complex data must be communicated to diverse stakeholders. Despite their growing importance, many existing implementations remain fragmented, domain-specific, or difficult for non-technical users to configure. This thesis addresses this gap by developing and evaluating a modular dashboard for Research, Technology, and Innovation (RTI) policy monitoring, designed to be adaptable across different policy contexts while remaining accessible to policymakers without technical expertise.

The research follows a design science methodology. First, a Systematic Literature Review (SLR) was conducted across four major databases, yielding a consolidated set of design principles for dashboards. These principles include visual clarity, interactivity, contextual information, accessibility, and provenance. Second, these principles informed the design and implementation of a prototype dashboard built on a three-tier architecture with a flexible multidimensional database schema. The system incorporates a guided configuration wizard, enabling the integration of heterogeneous datasets without requiring backend knowledge, and supports interactive visualizations linking indicators, subareas, and goals. Third, the system was evaluated through a twofold approach: (1) informed argumentation, comparing the implemented dashboard against the design principles derived from the SLR, and (2) semi-structured interviews with three expert participants involved in RTI policy evaluation.

The results demonstrate that the prototype effectively operationalizes principles of visual clarity, configurability, and systemic representation. The configuration wizard was particularly praised for transforming complex setup processes into accessible workflows. However, important gaps remain: accessibility features, provenance display, export/versioning, and systematic goal-indicator mapping require further development. The interviews confirmed the policy relevance of the system while underscoring the importance of explanatory support and decision alignment.

The thesis contributes both academically, by synthesizing dashboard design principles and demonstrating their applicability in the public sector, and practically, by delivering a functioning, extensible RTI dashboard prototype. Future work should prioritize accessibility, provenance, and advanced decision-support capabilities to fully realize the system's potential as a policy tool.

Contents

CHAPTER 1

Introduction

Dashboards have become a prominent means of communicating complex data in a way that supports analysis, decision-making, and transparency. In the public sector, the rise of open government data and the increasing demand for evidence-based policy have made dashboards an essential part of governance infrastructures. They are used to monitor progress toward strategic goals, track societal developments, and communicate insights to both policymakers and the public. At the same time, the design of effective dashboards remains a challenging task. Poorly designed interfaces risk overwhelming users, obscuring important information, or failing to align with decision-making needs.

In the domain of Research, Technology, and Innovation (RTI) policy, the need for effective dashboards is particularly pressing. RTI systems are inherently complex, encompassing diverse indicators, heterogeneous data sources, and multi-level policy frameworks. National and international bodies, including the OECD and the European Commission, have developed dashboards and scoreboards to monitor RTI performance, yet these often suffer from limitations such as domain-specificity, lack of adaptability, or reliance on static reports. Moreover, many existing dashboards assume a level of technical expertise that policymakers may not possess, thereby limiting their usability and impact.

This thesis addresses these challenges by asking three guiding research questions:

1. **RQ1:** Which design principles has the current literature discovered as relevant to building dashboards?
2. **RQ2:** Which of the design principles identified through the systematic literature are to be prioritized in the development of a dashboard intended for use in public-sector contexts?
3. **RQ3:** To what extent can such a system be configured by non-technical users with minimal backend involvement?

To answer these questions, the research follows a design science methodology. First, a Systematic Literature Review (SLR) was conducted to synthesize existing knowledge on dashboard design principles. The review consolidated findings from 25 peer-reviewed studies across information systems, visualization, and public administration. These studies highlighted recurring principles such as visual clarity, interactivity, contextual information, accessibility, and provenance, while also identifying challenges around customization, decision support, and long-term sustainability.

Second, informed by these principles, a prototype RTI dashboard was designed and implemented. The system adopts a modular architecture consisting of a Next.js frontend, a Spring Boot backend, and a PostgreSQL database using a snowflake schema. The design emphasizes configurability, introducing a five-step wizard that enables users to upload datasets, define areas and subareas, and configure indicators without technical expertise. Interactive features such as drill-down navigation, dimensional aggregation, and goal-subarea highlighting provide analytical depth while preserving simplicity of use.

Third, the prototype was evaluated through two complementary approaches. In the demonstration phase, the system was assessed against the design principles derived from the literature, highlighting areas of alignment and areas of partial implementation. In the empirical phase, three expert interviews were conducted with policymakers and analysts engaged in RTI monitoring. Participants were presented with a live demonstration using Austrian digitalization data and were invited to comment on usability, clarity, and relevance. Their feedback confirmed the strengths of the prototype—particularly clarity and configurability—while stressing the importance of explanatory support, provenance, and systematic goal-indicator mapping for real-world adoption.

The contributions of this thesis are twofold. Academically, it advances knowledge by synthesizing design principles into a coherent framework and demonstrating their applicability in a public-sector RTI context. Practically, it delivers a functioning, extensible RTI dashboard prototype that addresses core needs of policymakers and establishes a foundation for future development.

The remainder of this thesis is structured as follows. Chapter 2 reviews existing dashboards in the domain of research, technology, and innovation (RTI), identifying their strengths and limitations. Chapter 3 outlines the methodological approach, including the systematic literature review and the interview design. Chapter 4 synthesizes dashboard design principles from the literature and derives requirements for the prototype. Chapter 5 presents the implementation of the dashboard, describing its architecture, configuration process, and interface. Chapter 6 demonstrates the system in use, evaluating it against the identified design principles and reporting feedback from expert interviews. Finally, Chapter 7 summarizes the main findings, discusses contributions and limitations, and outlines directions for future research.

CHAPTER 2

State-of-the-Art

This section analyzes relevant papers that directly developed or evaluated dashboards in the domain of research, technology, and innovation (RTI), or in closely related policy areas. Unlike the broader literature review on dashboard design principles in Chapter 5, the focus here is on concrete implementations of RTI-related dashboards in the public sector.

Carli et al. [1] describe the development of a decision-support dashboard within the RES NOVAE project in Bari, Italy, aimed at energy governance in the context of smart cities. The Urban Control Center (UCC) aggregates multiple heterogeneous data streams—from municipal sensors, utilities, and official statistics—into a set of structured indicators designed for both operational monitoring and strategic planning. A distinguishing feature is the integration of optimization algorithms that allocate budgets across energy interventions such as public lighting or building retrofits. The dashboard architecture combines sectoral "decision panels" with an overarching urban control framework, offering drill-down and comparative functionalities. While the implementation demonstrates how energy-related RTI data can inform governance in a real city, its design is still strongly tied to the energy domain, raising questions about adaptability to other policy areas.

Chokki et al. [2] investigate dashboards in the context of open government data by designing the Namur Budget Dashboard (NBDash) in Belgium. Building on a systematic literature review, they identify sixteen design principles specifically tailored to open government data dashboards. These principles were implemented in a prototype that offers three levels of complexity—simple, less advanced, and advanced—to accommodate users with different levels of data literacy. The dashboard includes features such as bar charts sorted by value, drill-down capabilities, interactive filtering, and explanatory metadata. A controlled experiment with 108 participants showed that dashboards significantly increased perceived ease of use, trust, and engagement compared to stand-alone visualizations. The study highlights the effectiveness of dashboards for fostering transparency and citizen engagement, but also notes that overly detailed interpretative text may clutter the interface and reduce usability.

Ghazinoory et al. [3] propose a comprehensive RTI evaluation dashboard designed to capture the multidimensional nature of research and innovation policy. Their model incorporates input, output, outcome, and impact indicators, organized across five scientific fields and three types of state organizations, and validated through expert interviews and surveys. The dashboard visualizations are primarily based on radar charts, enabling comparative analysis of universities, ministries, and state-owned enterprises. The implementation emphasizes evaluation criteria such as efficiency, effectiveness, and sustainability, and was tested through case studies of Iranian universities. Although the dashboard represents one of the most structured attempts at a holistic RTI monitoring system, its reliance on expert-driven indicator weighting and radar visualizations raises concerns about transparency and interpretability when applied at scale.

Matheus et al. [4] analyze dashboards as tools for transparency and accountability in the governance of Rio de Janeiro. Their study reports on two dashboards developed at the city's Center of Operations: one for internal coordination of traffic management using real-time sensor and crowd-sourced data, and another for public dissemination of congestion information. The dashboards integrate open government data with citizen-generated inputs and are embedded in institutional processes of monitoring and response. This demonstrates the potential of dashboards to both empower citizens and support real-time operational decision-making. Yet the authors caution that dashboards can also impose predefined narratives on data, highlighting the risks of misinterpretation and over-reliance on visualization when data quality is insufficient.

Moura et al. [5] present the design of a business intelligence dashboard for the Court of Auditors of Pernambuco, Brazil, aimed at monitoring accountability processes. The initial system was fragmented, based on SQL Server, and had limited usability. The redesigned dashboard was implemented in Qlik Sense, consolidating data processing into the BI environment and improving reliability, interactivity, and analytical capacity. The development followed an agile methodology and delivered a tool that enables real-time analysis, customizable filters, and integration of diverse auditing data. The contribution lies in showing how BI platforms can replace legacy systems and provide scalable, more user-friendly dashboards for oversight institutions. Nevertheless, the study remains limited to one institutional context, leaving open questions about how transferable the approach is to other public-sector domains.

Musharu and Gómez [6] introduce a digitization dashboard for industry-level analysis of the ICT sector. Using design science methodology, the authors combined patent data, industry trend indicators, and structural analysis to produce a dashboard that enables strategic decision-making and foresight. The prototype was validated through heuristic evaluation and expert assessment, focusing on its ability to capture interconnections between technologies and highlight emerging areas of growth. The design emphasizes visualization of complex interdependencies and temporal developments, aiming to support policy and industry decisions in a fast-evolving sector. The study demonstrates the value of dashboards for sectoral RTI analysis, though the reliance on qualitative assessment and limited empirical testing suggests that broader validation with diverse stakeholders will be necessary before large-scale adoption.

Piquet et al. [7] focus on the design of a dashboard to monitor government-led STEAM education initiatives in Mexico. The case study centers on the "Matemáticas para Todos" program and uses a participatory design process involving eight stakeholder workshops. The dashboard integrates key performance indicators related to participation and educational outcomes, displayed through both spatial visualizations and performance charts. The iterative design ensured that the system was responsive to the needs of education authorities, while also aligning with government reporting requirements. This study illustrates the importance of involving users throughout the development process and shows how dashboards can be integrated into ongoing monitoring of RTI-related education policies. However, the prototype's integration with government IT infrastructure and its capacity for long-term sustainability were identified as challenges for future work.

Vila et al. [8] report on a municipal dashboard developed in Bahía Blanca, Argentina, for decision-making in the public sector. The system integrates open data across domains such as transport, health, and infrastructure into a single visualization platform. A particular emphasis is placed on composite indicators, which allow multiple metrics to be aggregated into synthetic measures that are easier for policymakers to interpret. The authors stress the importance of transparency in indicator construction, including metadata and data provenance, to mitigate risks of manipulation. Although the dashboard provides a valuable high-level overview of city performance, the study acknowledges that composite indicators can oversimplify complex realities and that dashboards must strike a careful balance between usability and representativeness.

Zuo et al. [9] present the design of InDash, a map-based dashboard for analyzing the industrial innovation environment in Jiangsu, China. The dashboard integrates 24 factors grouped into four categories—economy, infrastructure, inhabitance, and R&D—and visualizes them through spatial and multivariate analysis. The design was guided by user-centered methods and evaluated with thirty participants in a think-aloud study. The findings show that users were able to efficiently interpret complex data and reason about innovation environments with minimal training. The emphasis on spatial analysis and visual reasoning demonstrates the value of geovisualization in RTI monitoring. Nevertheless, the system lacked real-time data integration and relied on precompiled government datasets, limiting its responsiveness to rapidly changing innovation dynamics.

Ballantyne and Singleton [10] investigate the use of city dashboards based on composite indicators to guide place-based policy interventions in Liverpool, United Kingdom. Their dashboard combines indicators on transport, socioeconomic deprivation, housing, and innovation-related economic factors into an "Intervention Index" used for prioritizing investment decisions. The dashboard was co-developed with policymakers and applied in the context of transport settlements, showing how composite indicators can be operationalized in decision support. The study highlights the strengths of composite dashboards in simplifying complex phenomena and aligning indicators with concrete policy choices. At the same time, it warns of the risks of oversimplification and subjectivity in weighting, stressing the importance of transparency and stakeholder involvement in indicator design.

2.1 Limitations across existing RTI dashboards

Despite their diversity, the reviewed dashboards reveal recurring limitations. Several studies emphasize the domain-specificity of current implementations: dashboards such as those by Carli et al.[1] and Piquet et al.[7] were tightly tailored to energy governance or education programs, making transfer to other domains challenging. Others, such as Chokki et al.[2] and Vila et al.[8], highlight the risks of clutter, oversimplification, and dependence on composite indicators, which may obscure nuances of underlying data. The problem of sustainability also emerges, with prototypes like those of Musharu and Gómez [6] and Piquet et al.[7] lacking full integration into institutional infrastructures. Technical limitations include reliance on precompiled datasets rather than real-time updates (Zuo et al.[9]), insufficient scalability across policy contexts (Moura et al.[5]), and dependency on expert-driven weighting schemes that compromise transparency (Ghazinoory et al.[3]). Across cases, evaluation of long-term usage and actual policy impact remains scarce, with most studies relying on short-term experiments, workshops, or controlled validations.

CHAPTER 3

Methodology

This thesis follows the Design Science Research (DSR) methodology as an overarching framework for structuring the research process. DSR provides a systematic approach for designing and evaluating artifacts while ensuring both academic rigor and practical relevance. In particular, the Design Science Research Methodology (DSRM) proposed by Peffers et al. [11] serves as the conceptual backbone, consisting of six phases: problem identification and motivation, definition of objectives, design and development, demonstration, evaluation, and communication. Within this framework, two complementary evaluation strategies were adopted. First, informed argumentation was applied, in which the developed dashboard was systematically compared against design principles derived from the Systematic Literature Review (SLR). Second, semi-structured interviews with expert stakeholders were conducted to capture empirical feedback on usability, adaptability, and configurability. This twofold evaluation approach ensures that the artifact is assessed both conceptually, against literature-derived benchmarks, and practically, from the perspective of intended users.

To systematically identify relevant dashboard design principles, this thesis conducts a Systematic Literature Review (SLR) addressing *RQ1: Which design principles has the current literature discovered as relevant to building dashboards?*. The SLR follows guidance from Kitchenham on systematic literature reviews, as commonly applied in software engineering and information systems research, and is adapted to the scope of a master's thesis [12]. Concretely, the procedure comprised database selection, formulation of search strings, application of subject and discipline filters, screening using explicit inclusion and exclusion criteria, and full-text analysis. This streamlined process was designed to ensure transparency, comprehensiveness, and replicability while providing a robust empirical and theoretical basis for the principles identified.

3.0.1 Search Strategy

Database Selection

The databases were selected based on their extensive coverage of peer-reviewed journals and conference proceedings relevant to dashboard design and implementation, specifically within information systems, human-computer interaction, computer science, and management science domains. The selected databases include Scopus, Springer Nature Link, ACM Digital Library, and IEEE Xplore.

Search String

Across all databases, the following Boolean search string was employed:

```
("dashboard") AND ("design principle*" OR "design guideline*"
        OR "best practice*" OR "key factor*")
```

The wildcard asterisk (*) was used to capture singular and plural variations of keywords, ensuring broad coverage of synonymous or closely related terms commonly used in dashboard design literature. Searches were conducted in the **title**, **abstract**, and **keywords** fields where possible.

Use of Database Filters

Different filters were applied in each database because filtering options are not standardized across platforms. Each database provides its own subject classifications, discipline categories, and publication type filters, meaning that the exact same filtering strategy could not be applied everywhere. To ensure comparability, the chosen filters were always selected with the goal of narrowing down results to peer-reviewed, domain-relevant studies in information systems, computer science, management science, and related areas.

Search Results

Scopus

- **Initial results:** 478 records.
- **Subject area filters applied:** Computer Science, Engineering, Social Sciences, Business Management & Accounting, Decision Sciences, Economics/Econometrics & Finance. This reduced the count to 328.
- **Additional keyword filters:** *dashboard, visualization, data visualization, design, best practices, design principles, data analytics, dashboards, software design, key factors, decision support systems, key performance indicators, user interfaces.* This refined the set to 159 results.

The final corpus from Scopus prior to screening was **159** documents.

Springer Nature Link

- **Initial results:** 4134 records using the same core string.
- **Subject area filters:** Enterprise Architecture, Instructional Design, Data Integration, Smart Infrastructure, Interaction Design → 824 results.
- **Discipline filters:** Computer Science, Engineering, Business and Management → 687 results.
- **Subdiscipline filters:** User Interfaces and Human Computer Interaction, Information Systems Applications (incl. Internet), Information Systems and Communication Service, Information Storage and Retrieval → 245 results.

The final corpus from Springer Link prior to screening was **245** documents.

ACM Digital Library

- **Initial results:** 1014 records.
- **Publication type filter:** "Journals" only → 106 results.

The final corpus from ACM Digital Library prior to screening was **106** documents.

IEEE Xplore

- **Initial results:** 95 records using the same core string.

The final corpus from IEEE Xplore prior to screening was **95** documents.

3.0.2 Selection Criteria

Retrieved documents were evaluated against explicit inclusion and exclusion criteria to ensure relevance and methodological rigor:

Inclusion Criteria

(I1) The study explicitly addresses dashboards or performance dashboard systems.

(I2) The study discusses or proposes design principles, guidelines, best practices, or frameworks.

(I3) The publication is peer-reviewed (journals, conferences, or recognized academic outlets).

(I4) The study is available in English.

Exclusion Criteria

(E1) Studies mentioning dashboards only tangentially without explicit focus on design aspects.

(E2) Duplicate studies (keeping only the earliest or most comprehensive version).

(E3) Papers lacking explicit dashboard design guidelines or best practices.

(E4) Editorials, short opinion pieces, conference reviews, or poster abstracts lacking methodological depth.

3.0.3 Screening and Selection Process

Deduplication and Title/Abstract Screening

All documents retrieved were downloaded directly from the databases into Microsoft Excel, compiling a master list. Deduplication was performed manually by matching DOI, title, and abstract fields, removing duplicate records effectively. After deduplication, the remaining unique records were subject to title and abstract screening against the inclusion and exclusion criteria described above. Common exclusion reasons were insufficient focus on dashboard design or the usage of "dashboard" as a metaphor rather than an information system.

Following this stage, **90** papers remained and advanced to full-text screening.

Full-Text Screening

Full-text review of all 90 articles was conducted independently by the author. Each paper was rigorously evaluated according to the defined selection criteria. After detailed assessment, **20** papers were identified as highly relevant and methodologically sound, forming the final dataset for addressing the primary research question.

3.0.4 Data Extraction and Synthesis

From each selected article, the following data was systematically extracted:

- **Bibliographic details:** title, authors, publication venue, year.
- **Context/Domain:** public sector, private sector, education, healthcare, etc.
- **Core contribution:** what kind of design principles or guidelines are proposed or evaluated?
- **Methodological rigor:** whether the article provides empirical evidence, theoretical discussion, or a literature-based framework.

The synthesis of the results involved normalization of design principle terminology across papers, followed by counting occurrences to determine the frequency and prominence of each design principle. This resulted in a structured tabular summary comprising the following columns: **Paper**, **Original Design Principles**, and **Normalized Design Principles**. This approach ensured a systematic identification of common and significant dashboard design principles in the literature.

3.1 Interviews as Evaluation Method

To complement the literature-based evaluation through informed argumentation, this thesis also employs semi-structured interviews as a second evaluation method. The approach follows the general guidelines for conducting qualitative interviews as outlined by Runeson et al. [13] in the context of case study research. While their framework was originally developed for broader case study methodology, its principles were adapted here to structure the interview design, data collection, and analysis. Due to the limited scope of this thesis, only three interviews were conducted, focusing on live demonstrations of the system followed by guided discussion. No large-scale coding or inter-rater reliability checks were performed, but thematic coding was applied to ensure systematic analysis of participant feedback. This adapted methodology balances academic rigor with feasibility in a master's thesis context.

3.1.1 Purpose and Rationale

The interviews were conducted to evaluate whether the developed dashboard aligns with the needs of public-sector policy evaluation and to validate design decisions derived from the literature. This method was selected because it enables the collection of rich, qualitative insights into usability, adaptability, and configurability, which cannot be fully captured through technical testing alone. Semi-structured interviews further allow flexibility to pursue emerging themes while ensuring coverage of the core evaluation criteria.

3.1.2 Participant Selection

Three participants were selected based on their expertise and practical relevance to research, technology, and innovation (RTI) policy evaluation. The selection aimed to include individuals with backgrounds in policy design, data analysis, and digital governance. This ensured a diversity of perspectives while maintaining a strong connection to the intended user group of the dashboard. All participants had prior experience working with indicators or data-driven policy monitoring systems.

3.1.3 Interview Procedure

Each interview was organized as a live demonstration session in which the dashboard prototype was set up with a publicly available dataset. The author performed the configuration in front of the participant, after which the participant was invited to interact with the system. The interview followed a semi-structured format, guided by a predefined set of questions (see Appendix 7). The questions covered themes such as ease of setup, clarity of visualization, adaptability to different domains, and the extent to which non-technical users could operate the system. Additional probing questions were asked where relevant to clarify or deepen participants' statements.

3.1.4 Interview Setup

The demonstration was conducted using publicly available open-government data on regional digitalization in Austria, retrieved from the European data portal (`data.europa.eu`). Four datasets were integrated into the system: indicators for companies, indicators for households with internet access, indicators on ICT professionals, and two household datasets disaggregated by age and gender. These datasets were selected because they represent distinct but interrelated aspects of digitalization, thereby providing a meaningful test case for evaluating the dashboard's ability to capture systemic relationships.

The demonstration session began with logging into the administrator interface and launching the configuration wizard. The setup was carried out step by step, beginning with the definition of three subareas—*companies*, *households*, and *ICT professionals*—that together reflect key dimensions of Austria's digitalization landscape. The configuration wizard was then used to upload and map the datasets to the appropriate subareas, with indicator metadata such as units, dimensions, and sources specified during the process. Particular attention was paid to the handling of household datasets, where disaggregation by both age and gender was used to illustrate the flexibility of the dimensional architecture.

Following configuration, the demonstration highlighted the goal management functionality. A set of policy goals was linked to the defined subareas, and the interactive goal–subarea highlighting feature was used to show how indicators contribute to strategic objectives. This step demonstrated the alignment of operational data with higher-level policy aims, a central requirement for evidence-based evaluation.

The dashboard views were then presented sequentially. First, the area and subarea overviews were explored in the circular layout visualization, which illustrates hierarchical relationships between domains. Next, the subarea detail views were shown, including grouped time-series charts for each of the three subareas. Finally, indicator-level detail was demonstrated, using the modal view to switch between different visualization formats (bar chart, line chart, and tabular representation) and to apply dimensional selections and aggregations. This sequence of views illustrated the full navigation path from high-level monitoring to detailed analysis.

Upon completion of the demonstration, participants were asked a series of semi-structured questions to evaluate the usability, clarity, and configurability of the system. Their feedback is reported in the discussion chapter (Chapter 6.2).

The full list of datasets used in the demonstration, along with their descriptions and sources, is provided in Appendix 7.

3.1.5 Data Collection and Analysis

All interviews were recorded in note form, and partial transcripts were created to capture the participants' responses verbatim. The collected material was then analyzed through thematic coding, aligning responses with the three research questions of the thesis. Specific attention was paid to identifying recurring themes across participants, divergences in perspective, and direct references to design principles. The analysis was structured to trace how empirical feedback confirms, challenges, or extends the set of design principles derived from the literature.

One interview (Participant 3; see Appendix 7) was conducted in German and subsequently translated into English by the author for transcription and analysis. The translation prioritised semantic fidelity over literal phrasing; idiomatic expressions were normalised to standard academic English while preserving meaning. All quotations from this interview appearing in the thesis are based on the English translation.

3.1.6 Expected Contribution

The interviews provide empirical evidence to evaluate the artifact with respect to the identified research questions. In particular, they offer insights into (1) the applicability of literature-derived design principles in practice (RQ1), (2) which of the SLR-identified design principles can be meaningfully applied in a public-sector dashboard context (RQ2), and (3) the extent to which configurability enables non-technical users to set up the system with minimal backend involvement (RQ3). The results are discussed in detail in Chapter 6.

CHAPTER 4

Requirements

4.1 Dashboard Design Principles and Guidelines

This chapter synthesizes key dashboard design principles identified through the systematic literature review (SLR). These principles guide the development of a modular and adaptable dashboard solution intended for public sector applications, ensuring alignment with scholarly best practices and recommendations. The principles cover various contexts, including functional and visual features, interaction design, usability, and data governance.

Research on dashboard design principles varies significantly across industries. Since the establishment of the Open Government Partnership in 2011 [14], dashboard design research has intensified, particularly in the public sector, driven by an increased availability of open government data.

The foundational work by Few [15] defines dashboards as visual displays of essential information, emphasizing simplicity, clarity, and leveraging visual perception principles for rapid information processing. This foundation underscores guidelines such as enhancing data pixels, reducing visual noise, applying Gestalt principles, and organizing dashboard content to facilitate decision-making.

Building on this foundation, Few outlined core principles for effective dashboard design, emphasizing simplicity, clarity, and the importance of leveraging visual perception to support rapid information processing. Key guidelines include reducing non-data pixels, enhancing data pixels, applying Gestalt principles, and organizing content meaningfully to support decision-making at a glance.

From then on there has been a plethora of research papers and articles focused on the design of dashboards. We will try to summarize the most relevant ones in the following section.

Yigitbasioglu and Velcu [16] conducted a multidisciplinary literature review identifying critical dashboard design considerations for performance management. They differentiate between two essential categories of dashboard design features: *functional features* and *visual features*. Functional features describe what a dashboard can do, such as interactive elements or analytical capabilities. In contrast, visual features determine how efficiently and effectively the information is presented to the user. The authors emphasize the importance of achieving a functional fit between the dashboard's features and its intended purposes. Misalignment in functional features can lead to incomplete decision cues and suboptimal decisions, while poor visual design, such as excessive use of colours or decorative elements with low informational value, can confuse or distract the user.

They note that the process of visualization involves two distinct phases: *encoding* and *decoding*. Visualization is considered effective when the decoded perceptions accurately reflect the underlying data, and efficient when users quickly grasp maximal information with minimal cognitive effort. Hence, achieving a balance between visual complexity and informational utility is critical. Yigitbasioglu and Velcu [16] highlight that, although colours can improve visualization, their excessive use can impair decision-making by causing unnecessary distractions. Similarly, redundant graphical elements such as decorative frames or non-essential 3D objects might negatively affect users' focus on important data. To avoid these pitfalls, they recommend maximizing the data-ink ratio, a principle initially proposed by Tufte [17], which emphasizes using minimal graphical embellishments to represent the most relevant information clearly. To further reduce visual bias, the use of gridlines as visual aids in graphical presentations was suggested by Amer [18] and Amer and Ravindran [19].

Regarding functional features, dashboards should ideally fit on a single screen to provide a concise overview, but simultaneously allow interactivity to explore further details through drill-down capabilities. Thus, modern dashboards increasingly incorporate interactive elements, enabling dimensional analyses and deeper explorations of performance measures [15].

Summarizing implications for practitioners, Yigitbasioglu and Velcu stress the importance of aligning dashboard features closely with their intended purposes. For instance, drill-down and flexible data presentation features broadly support multiple dashboard goals, including consistency and monitoring, whereas scenario analysis features specifically support planning functions. However, including unnecessary features may increase cognitive complexity, while omitting essential features undermines dashboard effectiveness. Given that organizations might initially lack clarity about precise dashboard purposes, it is prudent to adopt flexible and upgradeable dashboard solutions.

The authors also underline that dashboard design must align with the users' cognitive characteristics and analytical needs. Some users may prefer accessing raw granular data rather than aggregated data, indicating the critical necessity of integrating drill-down capabilities. Without such features, analytical users may resort to external systems for detailed data, disrupting the decision-making workflow. Consequently, integration with data warehouses or Online Analytical Processing (OLAP) systems is recommended, ensuring users can seamlessly navigate between summary and detailed views.

Furthermore, based on cognitive fit theory, dashboards used for comparative tasks (spatial tasks) benefit from graphical representations, while dashboards supporting tasks focused on extracting specific values and detailed judgments (symbolic tasks) are better served through tabular representations. Given that dashboards typically serve comparative analyses of KPIs, graphical formats should be set as the default. Nevertheless, Yigitbasioglu and Velcu recommend providing users with the flexibility to switch between graphical and tabular displays to cater to varying cognitive styles and task requirements.

In conclusion, Yigitbasioglu and Velcu identify a set of visual design features considered universally beneficial, such as a restrained and purposeful use of colour, high data-ink ratio, and the strategic use of visual aids (e.g., gridlines). Conversely, they found functional features to be contingent upon dashboard purpose, task nature, and user characteristics. Thus, interactive flexibility, permitting dynamic shifts between data formats and granularity levels, emerges as a key dashboard design principle, allowing dashboards to effectively serve diverse user needs and cognitive styles.

Janes et al. [20] suggest that a useful dashboard has to pay attention to two aspects: choosing the "right" data and choosing the "right" visualization technique. Since we are developing a general tool and have no influence on the data that is going to be chosen in the end, we focused on their instructions on how to choose the "right" visualizations. They propose that the actual principles or guidelines depend on the usage scenario of the dashboard. Hence, they differentiate between "push" and "pull" dashboards, i.e. ones that aim to capture the users' attention and gain a large outreach, and the other where the user wants to get some specific information and uses the dashboard to get it. To create a successful dashboard in the "push" scenario, in which most of the dashboards in the public sector act, they suggest the following:

1. The dashboard should enable effortless access - the dashboard should be in an accessible place and easy to find.

2. The user should have the option to choose if he/she wants to interact with the data - the data should still be presented in a way that an interaction is not necessary for the data to be understandable

3. Organize dashboard content to ensure users can find and interpret information as quickly as possible. This includes always placing data in similar spots, which aims to allow the user to develop habits.

4. Direct the user's focus toward the most critical information on the dashboard. Use "pre-attentive" processing to highlight important data.

5. Display elements of the dashboard in visually appealing ways.

They also suggest paying attention to accessible design, for example not using color coding as the only means of conveying information, as this inhabits the capability of color-blind users to comprehend data on the dashboard.

Sarikaya et al. [21] provide a descriptive account of the dashboard landscape, analyzing 83 real-world examples and proposing a taxonomy of dashboard types, use cases, and features. While they do not define concrete design principles, their findings emphasize the growing diversity in dashboard forms, user expectations, and functions. Their work underscores the need for context-aware design principles that align with user roles, decision-making levels, and visualization literacy.

Bach et al. [22] identify a range of informative high-level guidelines for dashboard design, including recommendations related to visual perception, reducing cognitive load, interaction techniques, and visualization literacy . Still, they find that there is little knowledge about *effective* and *applicable* dashboard design, and how to support rapid dashboard design. They argue that most of the high-level decisions are out of control of designers, focusing instead on lower-level design decisions that the dashboard developer actually has control over. They make it clear, however, that determining what constitutes a "good" dashboard was outside the scope of their work.

Nevertheless, they identify and categorize 42 specific design patterns into two main groups: Content Design Patterns and Composition Design Patterns. Content patterns cover data abstraction levels (e.g., detailed datasets, aggregation, derived values), meta-information (e.g., sources, disclaimers, annotations), and visual representations (e.g., miniature charts, pictograms, trend arrows, gauges). Composition patterns address layout options (e.g., open, stratified, grouped), screenspace management (e.g., overflow, detail-on-demand, parameterization), structural relationships (e.g., single page, hierarchical), interaction types (e.g., exploration, drilldown, navigation), and color schemes (e.g., data encoding, semantic colors).

Additionally, Bach et al. distinguish six dashboard genres reflecting common combinations of these patterns: Static Dashboards, Analytic Dashboards, Magazine Dashboards, Infographic Dashboards, Repository Dashboards, and Embedded Mini Dashboards. These genres illustrate how pattern combinations align with user needs, tasks, and contexts, ranging from minimalistic static views to extensive analytical interactions.

Design tradeoffs discussed by Bach et al. revolve around balancing information abstraction, available screen space, the number of pages, and the degree of interaction. Decisions in one area typically necessitate adjustments in others, highlighting the complexity involved in achieving optimal dashboard design.

To validate and refine their findings, Bach et al. conducted a two-week dashboard design workshop with 23 participants from diverse backgrounds. Participants applied these patterns to their own dashboard projects, discussing challenges such as information overload, optimizing screen space, catering to different user expertise levels, providing contextual clarity, and accessibility considerations. The workshop demonstrated the utility of the design patterns as tools for structuring dashboard creation processes, clarifying design decisions, and facilitating collaborative discussions. Participants found the patterns effective in limiting design complexity, guiding structured decision-making, and serving as a practical checklist. The workshop underscored the necessity for deliberate, informed dashboard design processes that consider user-centric and context-specific requirements.

Martins et al. [23] conducted a literature review in the areas of interface design, data visualization, usability, UX and UI design, interaction design, and visual identity, to deliver dashboard design principles for the development of dashboards for business management, focused on these areas. Even though their main focus is on dashboards for business management, the guidelines they provide can be generalized to even the dashboards in the public sector. They underline that visual design is crucial to the clarification of data for it to be easily read and comprehended by the user. They argue that designing dashboards requires balancing usability with aesthetic considerations.

With this in mind, regarding **interface design** they instruct designers to pay attention to three main guidelines: page organization, colour and typography. They warn that attempting to display excessive information on a dashboard heightens the risk of overly compressing the information, negatively impacting readability. According to Martins et al., the use of a grid system is crucial to organize various graphic elements coherently and efficiently. They also emphasize the importance of blank spaces in the layout, as these help users distinguish between relevant and irrelevant information. With regard to **colour**, they suggest it should be used moderately. Dashboards should be initially designed in shades of grey, and colour gradually added. Lastly, concerning **typography** Martins et al. [23], citing Juice Analytics [24], summarize typography guidelines for dashboards by emphasizing readability as the primary goal. Headers should be visually distinct through variations in scale or weight, notes should be subdued into the background, and primary typographic emphasis should always highlight key data. The choice between serif and sans-serif typefaces must prioritize consistency and readability throughout the layout.

Martins et al. claim data analysis and visualization tools are crucial in representing high volumes of data at a glance, however they also underline their limitations. They propose the usage of tables when data comparison is needed, and colour maps to help reduce the mental process.

They also give a few high-level guidelines on usability, UX, UI, and interaction design including:

- A user-centered design process is essential, with usability serving as the core principle for enhancing user experience.
- To optimize user experience, the UX design process should begin with a user-focused investigation that identifies user needs, examines relevant data and management platforms, and incorporates a clear understanding of dashboard concepts and design principles.
- UI design is an iterative and interactive process - wireframes and prototypes should not be takes as the final solution.

- The project must have a meaning.

Smuts et al. [25] find that limited research was conducted into usability criteria of specific BI tools that support novice users. They find that novice users tend to stay within the predefined features of visualizations and rarely adapt or extend them for deeper analysis. Hence, development and understanding of complex dashboards is still a challenge for novices. With this in mind, they conduct a literature review to define 11 key design guidelines for BI tools for inexperienced users. They are: (1) Easy development process; (2) Guided development process; (3) Flexible customization process; (4) Immediate and interactive visual feedback; (5) User friendly data input for common data formats; (6) Automatic visualizations creation and suggestions with useful defaults; (7) Search, filter, and navigation facilities; (8) Multiple coordinated views for comparison; (9) History tools and storytelling (undo and redo); (10) Promote learning through explanations; (11) Saving, sharing and collaboration.

Dowding and Merrill [26] developed a heuristic evaluation checklist for assessing systems that produce information visualizations. Building on Nielsen's well-known usability heuristics [**?**], they extended the framework by incorporating three heuristics tailored specifically to visualization systems. The final checklist comprises 10 usability principles, supported by 49 usability factors designed to guide the evaluation of dashboards. The checklist was validated by domain experts, who found it intuitive to apply and reported that it successfully identified all relevant usability issues encountered during task execution.

1. **Visibility of system status** - Emphasizes providing users with clear and timely feedback. Dashboards should include clear headers, consistent icon design, and visible indicators of current system state and available actions.

2. **Match between system and the real world** - Encourages use of familiar language, intuitive ordering, and recognizable metaphors. Layouts should reflect logical sequences and use color and terminology consistent with user expectations.

3. **User control and freedom** - Focuses on giving users flexible navigation options, including the ability to undo actions, exit screens easily, and move back and forth across views without friction.

4. **Consistency and standards** - Ensures uniform use of visual and textual elements. This includes consistent naming conventions, layout structure, menu formats, and use of color throughout the interface.

5. **Recognition rather than recall** - Supports reducing memory load by placing prompts and labels where users naturally look. Related items should be visually grouped and important information highlighted consistently.

6. **Flexibility and efficiency of use** - Recommends providing multiple ways of interacting with the system (e.g., touch, keyboard), and allowing for user customizations or shortcuts to streamline frequent tasks.

7. **Aesthetic and minimalist design** - Advocates for visual simplicity by eliminating irrelevant data, avoiding visual clutter, and using space, typography, and layout strategically to highlight core information.

8. **Spatial organization** - Pertains to the logical layout of information, ensuring that users can easily locate and interpret data elements. The display should support contextual clarity and a sense of hierarchy.

9. **Information coding** - Involves the use of appropriate visual encodings such as symbols or icons that match the data type. Visuals should aid comprehension and avoid unnecessary realism.

10. **Orientation** - Refers to the ability of users to navigate and stay oriented within the visualization. Dashboards should offer controls for adjusting detail levels and support navigation with features like undo/redo and navigational context.

Zhuang et al. [27] propose a comprehensive evaluation framework based on a systematic review of 81 healthcare dashboards. The authors identify seven evaluation scenarios, grouped under three themes—interaction effectiveness, user experience, and system efficacy. Although originally intended for evaluation, these scenarios imply underlying design principles that dashboards should fulfill in order to perform well.

Under the theme of interaction effectiveness, three evaluation scenarios are discussed. The first, Task Performance, assesses how well a dashboard supports users in completing its intended tasks. High-performing dashboards in this category enable accurate, timely, and efficient task execution by reducing friction in navigation, clearly structuring information, and supporting decision-relevant actions. The second, Behaviour Change, considers whether a dashboard contributes to sustained positive changes in user behaviour, such as improved awareness, healthier practices, or better adherence to guidelines. Dashboards that facilitate reflection, learning, and self-monitoring are more likely to succeed under this criterion. The third scenario, Interaction Workflow, focuses on the intuitiveness and coherence of user interaction. Dashboards should minimize unnecessary complexity and cognitive load by aligning interactions with user expectations, reducing required steps, and supporting information-seeking behaviour in a natural sequence.

In the category of user experience, Perceived Engagement examines subjective user feedback regarding usability, satisfaction, aesthetics, and willingness to reuse the dashboard. This suggests that dashboards should not only be functional but also visually coherent, approachable, and rewarding to interact with. The second scenario in this category, Potential Utility, captures a dashboard's capacity to support unanticipated use cases or future functionalities. Dashboards should be flexible and extensible, encouraging exploratory use and supporting additional user needs beyond the original design scope.

Within the system efficacy theme, Algorithm Performance evaluates the accuracy, consistency, and responsiveness of algorithmic components embedded in dashboards. To satisfy this criterion, dashboards must ensure that analytical outputs are interpretable, robust, and well-aligned with user tasks. Finally, System Implementation addresses the practical deployment of dashboards within real-world settings. Effective dashboards must be designed with attention to contextual constraints, including data quality, system integration, institutional workflows, and the physical or technical environments in which they are deployed.

Taken together, these seven scenarios form a robust foundation for understanding dashboard quality from a design perspective. By interpreting each evaluation scenario as a set of design imperatives, Zhuang et al. contribute a valuable multi-dimensional perspective that is particularly relevant for dashboards operating in complex environments such as healthcare and the public sector.

Fan et al. [28] conducted an empirical study to investigate how older adults comprehend interactive data visualizations, using COVID-19 dashboards as a case context. Their work is particularly relevant for dashboard design in the public sector, where accessibility and clarity are essential for communicating information to broad and diverse audiences. Using the think-aloud protocol, the authors observed how 18 participants aged 60–78 interacted with five real-world dashboards sourced from institutions such as the WHO, Reuters, and 1Point3Acres. The visualizations incorporated various interactive features such as filtering, encoding, selecting, and elaborating, categorized using Yi et al.'s taxonomy of interaction techniques [29].

The study identified four cognitive stages in users' interaction with dashboards: (1) encoding visual information, (2) relating visual features to conceptual understanding, (3) associating new information with prior knowledge, and (4) recovering from errors. Participants often struggled with low visual contrast, ambiguous affordances, and interaction mechanisms requiring fine motor precision, such as hover-over tooltips or dense selection panels. These challenges were amplified when dashboard interfaces failed to align with users' expectations or lacked sufficient feedback mechanisms during trial-and-error exploration.

Based on these findings, Fan et al. derived five concrete design guidelines for improving dashboard accessibility and usability, particularly for older adults but applicable more broadly in user-centered dashboard design:

1. **Increase the legibility of visual designs:** Use high-contrast colors, large readable fonts, and reduce visual clutter by spacing out interface elements. These practices improve visual parsing, especially for users with age-related vision changes.

2. **Facilitate understanding of affordances:** Icons and interactive elements should be accompanied by plain-language labels to reduce ambiguity. Avoiding jargon and abbreviations further improves clarity.

3. **Match with user expectations:** Interface metaphors should align with widely used patterns—for example, spatial dashboards should mirror navigation metaphors from applications like Google Maps. Visual and spatial consistency across views reinforces users' mental models.

4. **Support trial-and-error and error recovery:** Dashboards should provide visible feedback after interactions, offer undo/redo functionality, and allow users to reset filters or views. These features reduce user anxiety and improve confidence during exploration.

5. **Ensure intuitive interaction:** Interaction design should minimize the need for precise cursor control and avoid hover-only features. Direct manipulation of data elements should be favored, and all interactions should include real-time feedback or alternative modes of input to support different motor capabilities.

While the study was conducted in the context of COVID-19 data visualizations for older adults, the authors note that these findings extend to general public-facing dashboards. The study highlights that accessible interaction design is not only a matter of inclusivity but also of functional clarity and trust in data systems.

Setlur et al. [30] reconceptualize dashboards as tools for "analytical conversations" rather than passive data displays. To support this cooperative framing, the authors introduce a set of 39 heuristics structured around five conversational stages—*initiation*, *grounding*, *turn-taking*, *repair and refinement*, and *closure*—as defined by Beebe et al. [31]. These stages serve as the conceptual backbone for encouraging more interactive, context-aware, and user-aligned dashboard design.

Going through each of the five stages, Setlur et al. explain how the interaction between the dashboard and the user should look like. In the **initiation** phase, users should be provided with information and explanations of different dashboard elements, and suggestions where to begin with the exploration of the dashboard. They also suggest providing users with curated information and metadata in this stage. The **grounding** phase should be used to build a "shared understanding of expectations and terms". One option to achieve this is to directly ask for priors and predictions from users. They reference Shi et al. [32] to illustrate that by actively soliciting users' own insights and expectations during the storytelling process, dashboards can tailor the information they present to be more engaging, relevant, and grounded in each user's context. In the turn-taking phase, they highlight the increased need for bi-directional communication between the user and the dashboard. Examples include providing tooltips or annotations on a user's request, filtering and aggregation, asking for personal information from the user, as well as including "analytical chatbots" with natural language query processing. They claim that constraining users from executing follow-up operations can disrupt the analytical workflow and often culminate in frustration when the dashboard lacks the mechanisms to address emergent queries or concerns. During the **repair and refinement** phase, it is important to incorporate mechanisms for verifying understanding and furnishing clarification whenever misunderstandings emerge. If the dashboard does not update when the information is outdated, irrelevant or false, this can lead to user frustration and sub-optimal user experience. Lastly, in the **close** phase, they remind that an often overlooked part of dashboard usage is the step of sharing insights that were gained during dashboard exploration. Setlur et al. suggest providing useful summaries of information or insights in a dashboard which can be shared beyond the dashboard itself. Allowing the option of past users providing context for future users, and producing a report in the end (with included discussion and conclusion sections) are alternate options for improving the experience during the close phase.

The 39 heuristics developed by Setlur et al. were iteratively refined through expert feedback from 16 visualization practitioners and validated through classroom exercises with 52 computer science and engineering graduate students. The heuristics address specific aspects of each conversational stage, such as providing contextual information during initiation (H1-H14), ensuring appropriate level of detail during grounding (H15-H24), supporting bidirectional communication during turn-taking (H25-H30), allowing users to redefine goals during repair and refinement (H31-H35), and providing clear takeaways during close (H36-H39). Their evaluation revealed that current dashboard designs tend to excel at initiation and grounding stages (with application rates of 74% and 76% respectively) but struggle significantly with turn-taking, repair and refinement, and close stages (with violation rates of 68%, 63%, and 95% respectively). These findings suggest that dashboard designers prioritize initial engagement but often neglect supporting the full analytical conversation cycle.

When students applied these heuristics to improve existing dashboards, they focused heavily on adding contextual information through text annotations, incorporating clear iconography to enhance meaning, implementing cross-view filtering to support turn-taking, and providing clearer summaries of key insights. Many students noted that they sacrificed some visual aesthetics for clearer communication, highlighting the tension between visual design principles and conversational effectiveness.

The authors propose that future dashboard authoring tools **should better anticipate conversational turn-taking, repair, and refinement**, suggesting opportunities for developing more interactive, responsive systems that can adapt to users' evolving analytical needs throughout the entire analytical conversation.

Ruoff et al. [33] address the challenges faced by users—particularly during crisis situations such as the COVID-19 pandemic—when interacting with complex public dashboards. They observe that even experienced professionals often struggled with dashboard navigation due to limited interactivity and usability constraints. To improve dashboard accessibility and comprehension, the authors propose integrating natural language interfaces (NLIs), enabling users to interact with dashboards conversationally, either by typing or speaking commands. Their work is grounded in a Design Science Research (DSR) approach, using iterative development cycles and evaluations involving domain experts and end-users.

Guided by Burton-Jones and Grange [34], which emphasizes the need for transparent and adaptable interaction, the authors formulate two meta-requirements for crisis-responsive dashboards:

- **MR1:** Adapt the surface structure of dashboards to support intuitive, natural interaction styles.
- **MR2:** Support independent learning and exploration of available interaction methods without external training.

Building on these requirements, Ruoff et al. [33] derive three design principles to guide the development of conversational dashboards:

1. **Enable natural language interaction** as an alternative to traditional graphical interfaces. Users should be able to query and interact with the dashboard using spoken or written language.
2. **Support mixed-mode interaction**, allowing users to switch flexibly between natural language input and conventional GUI-based controls. This hybrid approach accommodates varying user preferences and proficiencies.
3. **Integrate conversational onboarding mechanisms** to help users learn interaction capabilities through guided dialogues. This method, based on the concept of enactive learning by Gupta and Bostrom [35], facilitates self-directed exploration and builds confidence in using NLIs for dashboard tasks such as filtering, drilling down, or comparing data.

In a large-scale experimental evaluation involving 271 participants, the authors demonstrate that dashboards supporting natural language interaction—particularly when combined with onboarding—significantly improve user effectiveness and satisfaction. Their results suggest that mixed-interaction dashboards, blending traditional and conversational features, are not only more inclusive but also more efficient during high-pressure use cases such as public health crises.

Toreini et al. [36] explore an emerging area of dashboard design focused on attentive information dashboards, which leverage real-time eye tracking to monitor users' visual attention and provide individualized visual attention feedback (VAF). Their design principles aim to help users manage limited attentional resources during data exploration tasks by increasing awareness of viewing patterns and reducing cognitive overload. While their work presents promising directions for enhancing dashboard usability through adaptive interfaces, it remains largely experimental and technically demanding, with limited immediate applicability to public administration dashboards. Nevertheless, it offers a valuable outlook on how future dashboards might support user cognition more responsively, particularly in data-dense decision-making environments.

Ma and Millet [37] conducted a systematic literature review synthesizing design guidelines for immersive dashboards, leveraging technologies such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Although immersive dashboards are not yet widespread in public-sector contexts, their potential for supporting complex data exploration and collaborative decision-making suggests growing future relevance. The authors emphasize tailoring dashboards to user expertise, addressing limitations of traditional 2D displays such as constrained screen space and limited support for collaboration, while managing new challenges like navigation difficulty and high technical complexity. They define six key cross-cutting design criteria: accurate and expressive data presentation, direct and consistent interaction, compact and intuitive layout, flexible and customizable workspace, seamless collaboration support, and accessibility and user-friendliness. These guidelines, despite their initial context in immersive environments, provide valuable general insights for dashboard design across various sectors.

The authors identify several key areas where design considerations are critical:

First, dashboards must reflect the technical expertise and contextual needs of the target audience. This includes both domain experts (e.g., city planners, air traffic analysts) and non-expert users (e.g., general public), requiring interfaces that are adaptable and inclusive.

Second, immersive dashboards are proposed as a solution to the limits of traditional 2D displays, such as constrained screen space, poor support for collaboration, and challenges in visualizing complex multivariate relationships. However, they also introduce issues such as navigation difficulty, potential disorientation, and high setup complexity.

Third, immersive dashboards must support a wide range of data and interaction types. This includes real-time, large-scale, multidimensional, and dynamic datasets, presented through both standard (e.g., 2D/3D bar charts, scatterplots, PCPs) and advanced visualization forms (e.g., 3D scatterplot networks, decision trees). Interaction techniques should cover data transformation, filtering, zooming, selection, brushing, and linked views across multiple display modes.

Fourth, based on the literature reviewed, the authors define six cross-cutting design criteria for immersive dashboards:

1. **Accurate and expressive data presentation** – Dashboards should use declarative visual grammars (e.g., shape, color palette, depth cues) to clearly represent data. Different chart types should be employed for appropriate data structures, such as immersive scatterplots for clusters or node-link diagrams for reducing visual clutter.

2. **Direct and consistent interaction** – Interaction should be intuitive and proprioceptive, e.g., mid-air gestures, laser-pointer selection, egocentric navigation, and direct manipulation of axes. System feedback must align with user orientation via real-time cues and smooth transitions between views.

3. **Compact and intuitive layout** – Visual elements should be arranged within a limited space (e.g., semi-circle layout) to reduce unnecessary physical movement and cognitive load. Interaction panels and axes should also be manipulatable.

4. **Flexible and customizable workspace** – Dashboards should support different immersive setups (desktop VR, room-sized VR, mobile/web VR), allow users to modify views and parameters, and integrate diverse interaction models including keyboard, touch, voice, and gesture.

5. **Support for seamless collaboration** – Co-located and remote users should be able to analyze data together through features like multi-scale view sharing, avatars or visual representations of collaborators, speech-to-text tools, and real-time position tracking.

6. **Accessibility and user-friendliness** – Systems should be easy to configure and use, especially for novice users. This includes offering guidance materials, simplified UI with familiar metaphors, fallback keyboard–mouse interaction for non-immersive contexts, and avoidance of cognitive overload.

These guidelines, though developed for immersive contexts, point toward general best practices for designing dashboards that accommodate complex data, diverse users, and collaborative analysis—criteria increasingly relevant for public sector applications [37].

Matheus et al. [4] defined dashboards as "*the visualization of a consolidated set data for a certain purpose, which enables to see what is happening and to initiate actions*". They also differentiate between dashboards designed for governmental (internal) and public (external) use. They highlight the importance of proper data cleansing, and usage of proper vocabularies for metadata to solve the issues of understanding and interpretation. Based on their experience with two case studies presented in the paper, as well as literature on both private and public sector, they derived 10 design principles to serve as rules of thumb for designers. Following 10 design principles were proposed:

1. **Ensure data is accurate and precise** to avoid misleading users and to support clear understanding.

2. **Support customizable views** to enhance user insights; in certain contexts, it may be beneficial to develop separate applications tailored to specific tasks.

3. **Provide multiple views** to offer a more comprehensive understanding and reduce the risk of bias that can result from relying on a single perspective.

4. **Present data clearly** using charts, graphs, pictograms, etc., to show data for monitoring and analysis.

5. Show relationships between performance metrics and organizational desires, i.e. goals, to **support decision-making**.

6. **Support interactive features** to enable advanced insights.
7. **Incorporate drill-down and drill-up functionality** to enable users to explore data at varying levels of detail.
8. Design dashboards to **promote public values**, such as transparency, accountability, and civic engagement, while ensuring compliance with privacy regulations.
9. Strive for **real-time data updates**.
10. **Ensure institutional support** to enable citizens to provide feedback through independent and trusted channels.

Furthermore, they underline that dashboard design is not a trivial activity, and that there are many challenges and risks involved. They go on to summarize 15 main risks and challenges including *data privacy*, *limited knowledge and no suitable staff*, and *low data quality*. However, going into detail on all of these is out of scope of this paper.

Ghazisaeidi et al. [38] conducted a systematic literature review to identify key practical issues in developing performance dashboards, particularly focusing on the healthcare sector. They argue that traditional static performance reporting methods in healthcare result in inconsistent, incomparable, and static reports, thus significantly limiting their effectiveness for informed decision-making. Consequently, the healthcare sector increasingly requires dynamic and interactive tools such as dashboards to measure, monitor, and manage performance effectively.

Their review synthesizes key findings into four main domains essential for developing high-quality performance dashboards:

1. **Performance Measures (PMs) and Key Performance Indicators (KPIs) Development:** KPIs form the basis for performance measurement, guiding managers in tracking progress against specific targets. According to the sources reviewed by Ghazisaeidi et al., KPI selection must comprehensively consider multiple performance dimensions and stakeholder viewpoints, employing structured reference models like the Balanced Scorecard or Performance Pyramid. KPIs should align explicitly with organizational goals and strategic objectives [39]. The creation of a metrics dictionary—detailing metrics' names, purposes, equations, targets, thresholds, measurement units, reporting frequencies, and data sources—enhances their clarity and usability [40]. Moreover, establishing hierarchical relationships between KPIs (lead and lag indicators) is crucial for enabling deeper analytical insights and drill-down capabilities [41].
2. **Data Sources and Data Quality:** Reliable identification of data sources and ensuring data quality are critical for dashboard efficacy. Dashboards frequently integrate data from varied and often inconsistent sources, necessitating standardization

of data definitions and resolution of discrepancies. Feasibility of KPIs heavily depends on data availability, possibly requiring new data collection processes. Efforts aimed at improving data quality significantly impact dashboard usability [38].

3. **Integration of Dashboards with Source Systems:** Dashboards require robust IT infrastructure for efficient data capture, integration, and presentation. According to Rasmussen et al., cited by Ghazisaeidi et al., data warehousing and Online Analytical Processing (OLAP) infrastructures are essential for flexible reporting, multidimensional analysis, and interactive features like drill-down capabilities. Furthermore, efficient backend processes determine data refresh rates, enabling real-time or periodic updates (e.g., hourly or weekly) [42].

4. **Information Presentation:** The visual and functional design of dashboard interfaces should correspond closely with users' cognitive tasks and analytical skills. Ghazisaeidi et al. highlight from their literature review that according to cognitive fit theory, graphical visualizations are better suited for tasks involving relationships, such as comparisons and pattern recognition. In contrast, tables are preferable for detailed value extraction tasks. Providing flexibility for users to toggle between graphical and tabular views improves dashboard effectiveness. Functional dashboard features—including real-time notifications, drill-down options, and scenario analyses—further enhance their decision-support capabilities [38].

Ghazisaeidi et al. [38] conclude that addressing these key domains systematically results in performance dashboards capable of consistent performance measurement, rapid identification of outliers, in-depth analysis of performance issues, and more effective strategic planning in healthcare management.

Vila et al. [8] emphasize that human visual systems are exceptionally effective at detecting trends and patterns, significantly enhancing humans' ability to gain insights when analyzing data if visualizations are well-designed. They argue that even when specific analytical questions are undefined, properly designed visualizations can guide decision-makers toward identifying and solving problems.

However, Vila et al. note a significant gap regarding the availability of technological tools capable of efficiently processing open government data to generate actionable insights for informed decision-making in the public sector. They underline that dashboards are particularly effective for this purpose because they support various forms of user interaction, such as abstraction or detailed zooming, allowing users to focus selectively on different information aspects [8].

To enhance the representativeness and effectiveness of city dashboards, Vila et al. stress that key performance indicators (KPIs) must be carefully designed. They propose using composite indicators—aggregations of single indicators that are typically weighted differently. Such composite indicators, however, are sensitive to adjustments and potentially vulnerable to manipulation. Therefore, transparency in their methodological computation through data provenance and metadata becomes essential. **Data provenance**, defined as the information detailing the derivation history of data.**Metadata**, providing contextual dataset information. Both are crucial to ensure data quality, veracity, and reliability [8].

Vila et al. also advocate for strategically directing user attention on dashboards, ensuring the most important information is presented first. They highlight several essential interface features:

- All relevant information should be viewable on a single screen, clearly interconnected to facilitate meaningful conclusions.
- Visualization should provide adequate contextual data to avoid misinterpretation but exclude redundant details to prevent information overload.
- Visualization selection should align with data characteristics, and dashboard elements should be strategically arranged to enhance usability.

As a result, the effectiveness of open data-based city dashboards is directly constrained by each local government's level of openness and data availability. Vila et al. suggest that providing clear data provenance—especially regarding the sources and data collection processes—would significantly improve the utility and trustworthiness of public sector dashboards [8].

Nasir et al. [43] offer a useful synthesis of common dashboard design principles across domains. However, since many of the principles they outline are derived from works already included in this review (e.g., Martins et al., Sarikaya et al., Bach et al.), the study was excluded from detailed analysis to avoid redundancy. The paper served instead as a meta-confirmation of cross-domain relevance of the selected design principles.

In the following paper by Nasir et al. [44], the same authors shift their focus toward the integration of information governance (IG) into the dashboard design process, arguing that dashboards must not only be visually and functionally well-designed but also adhere to governance principles to ensure data reliability, integrity, and security. They emphasize that dashboards are not merely standalone visualization tools but are deeply dependent on the quality and governance of the underlying data. To address this, the authors propose embedding IG as a foundational layer in the development of their work-in-progress Information Dashboard Design Ontology (IDDO).

Using a narrative literature review, they synthesize insights from three well-established IG models—the Information Governance Reference Model (IGRM), the Information Governance Implementation Model (IGIM), and the Information Governance Maturity Model (IGMM). Based on this synthesis, they derive eight core IG principles that they argue should guide dashboard design: **Quality**, **Security**, **Compliance**, **Integrity**, **Availability**, **Transparency**, **Accountability**, and **Effectiveness**. Each of these is explicitly aligned with previously identified common dashboard design principles, such as clarity, usability, and flexibility.

For instance, quality is aligned with the need for dashboards to be easy to understand and free from unnecessary detail; accountability supports structured layouts and role clarity in information handling; security ensures the system's functionality by protecting data from breaches or unauthorized access. This novel integration reframes dashboard design not only as a task of visual and interaction design, but also as one of responsible data stewardship, particularly important in public-sector contexts where transparency and trust are paramount.

Zuo et al. [9] present a user-centered approach to dashboard design by developing *InDash*, a map-based dashboard aimed at supporting decision-making in the context of industrial innovation environments (IIE) using open government data. The authors emphasize the necessity of aligning dashboard functionality with stakeholder needs through a structured requirements analysis and iterative design process.

The authors derive five high-level design requirements for dashboards based on user interviews and domain analysis: (1) **View the topic, factors, and values at a glance** – dashboards must present an overview of all relevant dimensions (e.g. economy, infrastructure) to support orientation and hypothesis formation; (2) **Show spatial information at different granularities** – providing spatial context at both regional and city level supports location-based reasoning; (3) **Support visual reasoning** – juxtaposed visualizations should facilitate tasks such as comparison, correlation, and trend identification; (4) **Support interactivity** – users should be able to filter by thematic categories and geographic regions based on their interest; and (5) **Ensure ease of use** – dashboards must be self-explanatory and usable without intensive training.

To implement these requirements, *InDash* employs multiple linked panels featuring diverse visualization types including radar charts, matrix heatmaps, and parallel coordinates. The layout is organized hierarchically, progressing from general to specific information, and spatially aligned with standard web reading flows. Visual panels are arranged from top to bottom and left to right based on abstraction and granularity, with spatial overviews positioned prominently. Furthermore, the authors stress several usability principles: clear panel division, logical arrangement, consistent color schemes, and simple interactions, all of which aim to reduce cognitive load and facilitate intuitive use.

The study demonstrates that a dashboard designed according to these principles enables users to perform exploratory tasks efficiently, even without prior training, validating the role of user-centered, spatially aware design in enhancing the utility of open government data.

Chokki et al. [2] conducted a systematic literature review and an experimental case study to explore dashboard design principles specifically aimed at increasing citizen engagement with Open Government Data (OGD). They began by highlighting that traditional individual visualizations often lack effectiveness for citizen engagement, as these visualizations typically cover only a limited portion of available data, diminishing perceived value and relevance. Dashboards, by contrast, offer a more holistic way to present data by integrating multiple indicators into a unified graphical interface.

To identify dashboard design principles suitable for the OGD context, Chokki et al. systematically reviewed existing literature across multiple databases, including academic sources and grey literature. The authors initially identified 274 papers, ultimately narrowing this down to 24 publications after applying rigorous filtering criteria. From these, they extracted and adapted 16 key dashboard design principles relevant for the OGD domain. These are:

1. **Collect accurate and precise data** - Refrain from presenting unclear or untrustworthy data and metadata.
2. **Ensure your data makes sense** - Make sure data is consistent before and after data aggregations or transformations.
3. **Consider audience** - Dashboards should be tailored to the target audience or offer versions suited to different user types.
4. **Use best visualization practices** - Citizens prefer clear and visually appealing representations that make data easy to grasp (e.g. bar charts ordered by value).
5. **Use the right types of charts** - Select charts based on the data type and audience to ensure clarity.
6. **Provide easy-to-use tools** - Offer free, user-friendly tools that enable dashboard creation, thereby enhancing public understanding of published data and encouraging its reuse.
7. **Clear presentation** - Dashboards should be visually well-structured, responsive to screen size, prioritize key information, group related content, and follow basic UX/UI principles to ensure clarity and usability.
8. **Provide context and data interpretation support** - Include metadata, titles, and labeled axes to help with interpretation.
9. **Think about data literacy levels** - use clear, consistent, and familiar language to accommodate varying levels of data literacy and make dashboards accessible to all users.
10. **Ensure data is up to date** - Clearly indicate when data was last updated or extracted to support informed and timely decision-making by users.
11. **Allow access to data source** - Provide links to original data sources to support transparency, enable customization, and build user trust.
12. **Check for personal data/outliers** - Safeguard citizen data by aggregating information and preventing identifiability to ensure confidentiality and address privacy concerns.

13. **Interaction support** - Incorporate features like hover details, filters, and drill-down capabilities to accommodate varying user needs and enhance data exploration.
14. **Ensure feedback support** - Enable user feedback during and after development to continuously improve dashboards, and consider features for reporting issues like fraud to foster trust and engagement.
15. **Customization** - Allow citizens to tailor dashboards by providing the necessary information for reuse and modification, fostering trust and encouraging active engagement.

To validate these design principles, Chokki et al. applied them to create the Namur Budget Dashboard (NBDash), using actual open datasets from the city of Namur, Belgium. The dashboard incorporated interactive features allowing users of varying expertise levels to explore the data comfortably. An experimental study involving 108 participants compared citizen engagement between the well-designed NBDash and standard individual visualizations from Namur's existing data portal. Results indicated that citizens found the dashboard significantly easier to use and understand, better suited to diverse skill levels, and more trustworthy regarding data quality and veracity. The findings strongly supported the hypothesis that well-designed dashboards substantially improve citizen engagement with OGD compared to individual visualizations.

Maheshwari and Janssen [45] note that public values are different in different public sector organizations and are often difficult to measure. They argue that these are distributed over different stakeholders and are difficult to relate. They also suggest that dashboards can enhance performance accountability in public organizations while significantly reducing overall costs. They go on to summarize the benefits of using performance dashboards and provide 8 design principles to be used when developing them:

1. **Allow metric customization**, i.e. allow the organizations to pick metrics relevant to their situation.
2. **Use available data resources and prioritize key metrics** during data updates.
3. **Link dashboard elements to performance metrics**
4. **Enable analysis of the impact of alternative improvements** - enable organizations to use the dashboard as a tool for exploring 'what-if' scenarios.
5. **Instant visual communication** – dashboards should use clear visuals (e.g., charts, colors, icons) to present precise and relevant information for quick performance insights.
6. **Multi-level design** - dashboards should serve various stakeholder needs, not just executives, to maximize value and reduce costs. Integrating multiple views into a connected system supports broader, more effective use.

7. **Support with data comprehension** - relationships between different KPIs and organizational goals should be clear and transparent.

8. **Continuous improvement and development** – dashboards should support performance tracking over time to drive learning and progress.

Lafortune et al. [46] describe the development and methodological framework of the *Government at a Glance (G@G)*dashboard published by the OECD. While their work does not focus on dashboard interface or interaction design, it is notable for its structured approach to selecting and evaluating public governance indicators. G@G adopts a dashboard model that emphasizes disaggregated, domain-specific indicators over composite indices, aiming to support transparent benchmarking and informed policy-making.

The authors introduce a five-criteria framework for assessing the quality of dashboard indicators. Indicators should be:

1. **Action-worthy** – relevant to meaningful public policy concerns;

2. **Actionable** – provide insights that can guide specific reforms;

3. **Behavioural** – measure actual implementation, not just formal rules;

4. **Valid** – capture the intended phenomenon accurately;

5. **Reliable** – produce consistent results across time and context.

Although not directly applicable to visual design or user interaction, this framework can inform **the selection and structuring of indicators in the backend** and **data architecture of public sector dashboards**.

Ghazinoory et al. [3] proposed a comprehensive, multidimensional approach to designing a dashboard aimed explicitly at evaluating Science, Technology, and Innovation (STI) in public sector organizations. Their work highlights the inherent complexities in STI evaluation, driven by diverse stakeholders, varying organizational objectives, distinct scientific disciplines, and the multifaceted nature of innovation processes. Recognizing these challenges, the authors developed an evaluation dashboard that systematically incorporates these dimensions into a unified framework.

The dashboard approach explicitly considers several critical evaluation dimensions, including efficiency, effectiveness, relevance, utility, sustainability, and stakeholder perspectives. Their conceptual model incorporates multiple layers: identifying key stakeholders, mapping stakeholders to their respective roles and contributions in the STI process, and finally linking these roles to corresponding indicator categories (input, output, outcome, and impact). Four key stakeholder groups—STI policymakers, researchers and technicians, industry beneficiaries, and the general public—were identified, each aligned with distinct indicators reflecting their roles in the innovation ecosystem.

One of the central contributions of their study is the structured classification of indicators. These indicators are organized along three dimensions: type of indicator (input, output, outcome, impact), type of state organization (universities/research institutes, ministries/executive organizations, state-owned companies), and scientific fields (natural sciences, human sciences, social sciences, health sciences, engineering sciences). Consequently, the final STI evaluation dashboard developed by the authors comprises multiple radar charts representing performance metrics tailored specifically to the organizational type and scientific domain. Each radar chart visually illustrates performance scores for key indicators within the defined categories, facilitating intuitive comparative analyses across organizations.

Their methodological approach involved design science, employing qualitative and quantitative methods such as structured interviews and expert surveys to validate indicator selection. After identifying a comprehensive pool of indicators, a set of relevant metrics for each scientific field and organizational category was refined and weighted through expert consultations. The authors subsequently validated the resulting dashboard through a practical case study involving nine Iranian universities, verifying the dashboard's effectiveness in accurately capturing and differentiating organizational performance.

Summarizing their key findings, the authors emphasize several pivotal principles for effective STI dashboard design:

First, dashboards must clearly reflect stakeholder-specific roles in the STI process, ensuring indicators resonate meaningfully with distinct stakeholder needs. Policymakers require indicators capturing societal relevance, researchers and technical personnel require metrics reflecting research efficiency, industry beneficiaries need outcome-based indicators assessing effectiveness, and the general public benefits from impact-oriented metrics evaluating broader societal utility.

Second, indicator selection must account for differences across scientific fields and organization types. The evaluation dashboard thus incorporates tailored metrics for various scientific disciplines (e.g., human sciences vs. engineering) and organizational missions (e.g., universities focused on knowledge generation versus ministries addressing societal issues).

Third, the dashboard should facilitate comparative analyses at two distinct levels: internal (organization's current versus past performance) and external (performance relative to peer organizations). Such comparative capabilities enable targeted policymaking and resource allocation based on rigorous evaluations.

From a policy perspective, Ghazinoory et al. advocate a semi-centralized organizational approach to STI evaluation, emphasizing clear separation between data collection and analytical validation processes. They further stress the necessity of aligning evaluation indicators closely with organizational missions, scientific disciplines, and the broader societal contexts in which STI projects operate. Continuous, structured feedback enabled by the dashboard can foster iterative organizational learning and sustained performance improvement. Ultimately, their proposed dashboard provides policymakers with a structured, evidence-based mechanism to identify performance bottlenecks, optimize budget allocations, and enhance overall STI policy effectiveness.

Strand [47] offers a conceptual framework for understanding how indicator dashboards function within different models of evidence-informed policymaking. Rather than proposing technical design guidelines, Strand introduces a typology—referred to as the "evidence stars" model—that categorizes dashboards based on the maturity and complexity of the advisory ecosystem they support. The framework, developed within the context of EU science-for-policy work, emphasizes the evolving relationship between indicators and governance, suggesting that dashboard design must reflect not only data but also institutional values and contextual complexity.

The five-star typology begins with dashboards that reflect basic truthfulness and integrity (1-star) and progresses through relevance and salience (2-star), pluralism and honest brokering (3-star), and reflexivity and learning (4-star), culminating in dashboards that support co-production of knowledge with stakeholders (5-star). Each additional "star" introduces greater epistemic diversity and responsiveness to contextual factors. At the highest level, dashboards are no longer mere reporting tools but act as facilitative infrastructures for dialogue and mutual learning among policymakers, experts, and the public.

While Strand does not provide concrete design prescriptions, the typology implies that the function and structure of a dashboard should correspond to the governance model in which it is embedded. Simpler dashboards (e.g., 1–2 star) may suffice in hierarchical, command-and-control contexts, while more participatory, context-sensitive environments (3–5 star) require dashboards that accommodate uncertainty, value pluralism, and deliberative input.

Cepero et al. [48] developed a structured, user-centered visualization framework specifically tailored for smart city dashboard applications. The framework, created through Jabareen's methodology [49], incorporates systematic mapping of relevant data sources, categorization of key concepts, and iterative validation by domain experts. This rigorous methodological approach ensured the comprehensiveness, coherence, and practical applicability of the resulting guidelines.

The proposed framework encompasses six distinct phases, beginning with understanding the user context and culminating in the evaluation of the visualization solution. While each phase is integral, several stages provide particularly actionable guidelines for dashboard developers, notably the *analysis of visualization methods* and the *visualization design development* phases.

In the phase of *analysis of visualization methods*, Cepero et al. emphasize the necessity of matching visualization methods explicitly to the patterns of urban data analysis required by users. They propose a systematic categorization of visualization techniques based on analytical purposes:

- **Monitoring and Control**: Dashboards should leverage visual elements such as gauges, traffic lights, and line graphs for rapid identification of deviations or anomalies in data.

- **Distribution and Comparison**: Bar charts, histograms, and boxplots are recommended for visualizing distributions, comparisons, and categorizations clearly and concisely.

- **Trend Analysis**: Line graphs, time series plots, and trend lines effectively illustrate changes over time, enabling users to recognize temporal patterns efficiently.

- **Spatial Analysis**: For geographical or spatial data, maps and heatmaps are advocated, ensuring precise representation and spatial context clarity.

- **Textual Data Analysis**: Word clouds and network diagrams facilitate the exploration and summarization of textual or relational data.

- **Uncertainty Communication**: Error bars, confidence intervals, and transparent visual encoding effectively communicate uncertainties inherent in urban data, enhancing trust and interpretability of visualizations. Cepero et al. further illustrate these recommendations with practical guides and visual examples, allowing dashboard developers to quickly select appropriate visualization methods aligned with user goals.

In the subsequent *visualization design development* phase, Cepero et al. [48] provide specific principles for effectively presenting visual information. They strongly encourage developers to ensure visual clarity and simplicity, highlighting several detailed recommendations:

- Clearly label visualizations with titles and legends to facilitate immediate comprehension. Maintain traceability by including references or metadata to the data sources, supporting transparency and credibility.

- Provide sufficient contextual information (such as baseline values, thresholds, or reference lines) to aid users in interpreting data accurately.

- Avoid redundant visual elements and decorative effects, particularly cautioning against unnecessary 3D visuals, which can distort interpretation and complicate the visual decoding process.

- Adhere to the principle of maximizing the *data-ink ratio* [17], emphasizing simplicity and minimalism to enhance clarity and reduce visual clutter.

- Apply Gestalt principles such as proximity, similarity, and continuity [15] strategically to group related data elements visually, thereby enhancing pattern recognition and data readability.

Finally, the authors underscore the necessity of an effective evaluation phase, suggesting multiple evaluation techniques suitable for dashboard validation, including usability studies, user studies, controlled experiments, and case studies [48]. Such structured evaluations ensure the dashboard remains user-centered, relevant, and genuinely useful in practical urban contexts.

In summary, Cepero et al.'s user-centered visualization framework provides detailed, practical guidelines particularly relevant for dashboard developers working with urban data, highlighting the critical importance of aligning visualization choices to data analysis goals and ensuring clarity and efficiency through sound visual design principles.

The comprehensive synthesis presented in this chapter highlights several essential dashboard design considerations prevalent in existing literature. Common themes include visual clarity, cognitive efficiency, interactive flexibility, accessibility, and robust data integration practices. While the diversity of identified principles reflects varied sectoral requirements and technological capabilities, recurrent recommendations such as minimalist visual designs, user-centric interactivity, contextual adaptability, and support for different user expertise levels emerge as particularly critical. These synthesized design principles will directly inform the practical development and implementation of the modular and adaptable dashboard solution presented in the following demonstration chapter.

4.2 Design Principles Synthesis

To ensure a structured and literature-backed assessment of the developed dashboard, a consolidated set of design principles was systematically derived from papers in Section 4.1. The resulting normalized principles facilitate clear comparisons and comprehensive analysis across diverse academic sources. A detailed mapping of these original and normalized principles is presented in the Appendix (Table 1). Figure 4.1 summarizes the frequency of each normalized design principle across the reviewed literature, reflecting their relative prominence and significance.

Visual Clarity and Clear Presentation. Visual clarity emerged as the most consistently emphasized principle across the literature, appearing in nine different studies. This principle encompasses Few's [15] foundational emphasis on simplicity and clarity, Martins et al.'s [23] focus on interface organization and typography optimization, and Cepero et al.'s [48] recommendations for clear labeling and visual simplicity. The normalization process consolidated various expressions of this concept—including "clear presentation," "visual communication," "legibility of visual designs," and "aesthetic and minimalist design"—into a unified principle recognizing that effective dashboards must prioritize immediate comprehension over decorative elements. Fan et al.'s [28] empirical study with older adults particularly highlighted how visual clarity directly impacts accessibility, while Chokki et al. [2] demonstrated its importance for citizen engagement with open government data. This principle will be central to the dashboard implementation, as it directly influences user adoption and effectiveness in public sector contexts where diverse user groups must quickly interpret information.

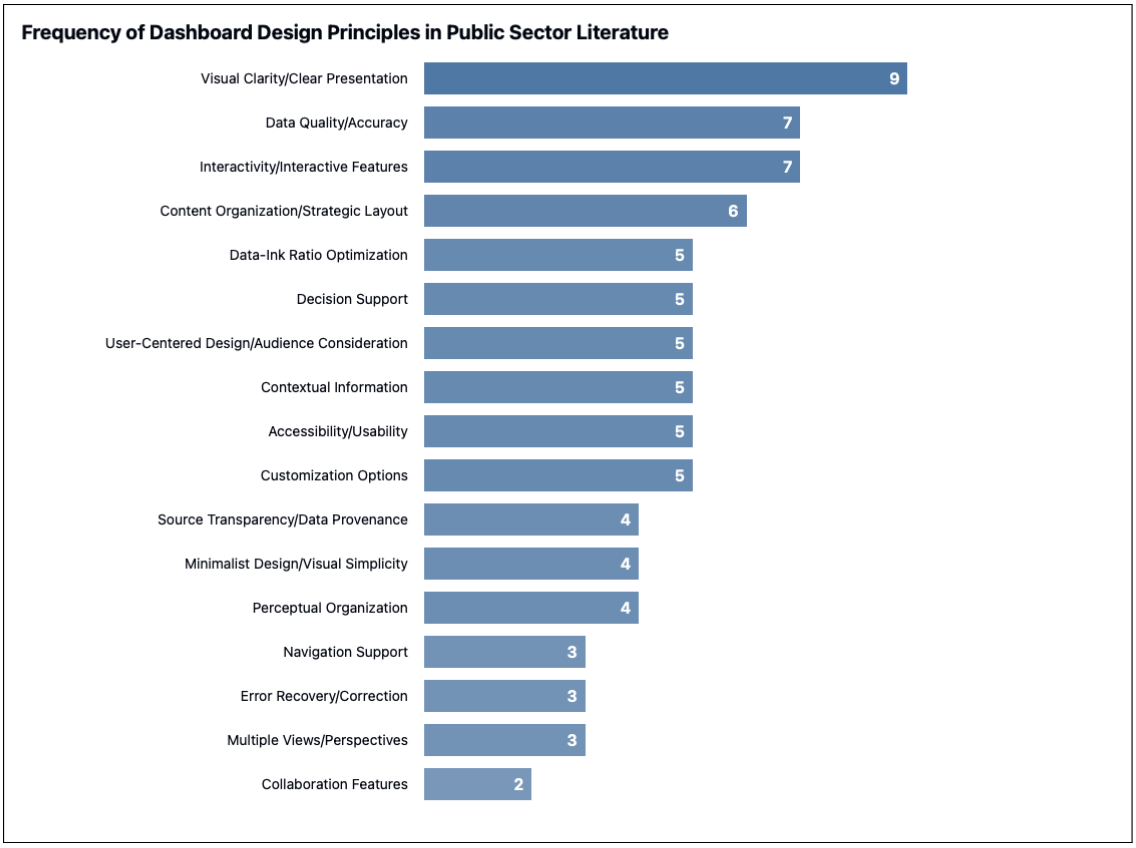


Figure 4.1: Frequency of dashboard design principles identified in the literature review

Data Quality and Accuracy. Data quality and accuracy appeared as a critical concern across seven studies, reflecting the fundamental requirement that dashboards must present trustworthy information. This normalized principle emerged from various original formulations including Matheus et al.'s [4] "ensure data is accurate and precise," Chokki et al.'s [2] emphasis on "accurate and precise data collection," and Nasir et al.'s [44] integration of information governance principles emphasizing data quality management. Ghazisaeidi et al.'s [38] healthcare-focused review particularly stressed how data quality issues significantly impact dashboard usability, while Vila et al. [8] highlighted the importance of data provenance and metadata for establishing trust. The normalization process recognized that beyond mere accuracy, this principle encompasses data consistency, reliability, and currency. This principle is considered within scope but primarily addresses backend data management processes rather than front-end dashboard design features, requiring collaboration with data providers to ensure implementation.

Interactivity and Interactive Features. Interactive capabilities were emphasized in seven studies as essential for modern dashboard effectiveness. This principle consolidated various interaction-related concepts including Yigitbasioglu and Velcu's [16] drill-down capabilities, Smuts et al.'s [25] immediate and interactive visual feedback, and Setlur et al.'s [30] comprehensive framework for analytical conversations through turn-taking and bi-directional communication. Matheus et al.'s [4] public sector focus highlighted interactive features as crucial for transparency and civic engagement, while Ruoff et al.'s [33] natural language interaction research suggested emerging directions for dashboard interfaces. The normalization recognized that interactivity encompasses not only basic filtering and drill-down capabilities but also sophisticated features like conversational interfaces and adaptive responses. This principle is fully within scope and will be implemented through modular interaction components, though advanced features like natural language processing may be reserved for future development phases.

Content Organization and Strategic Layout. Strategic organization of dashboard content appeared across six studies, reflecting the critical importance of information architecture in dashboard design. This principle emerged from Few's [15] emphasis on organizing content meaningfully, Janes et al.'s [20] focus on organizing content for quick interpretation, and Dowding and Merrill's [26] spatial organization heuristic. Martins et al.'s [23] interface design guidelines emphasized grid-based layouts and white space utilization, while Cepero et al. [48] stressed applying Gestalt principles for perceptual grouping. The normalization process recognized that effective content organization involves both macro-level layout decisions and micro-level arrangement of visual elements to support natural scanning patterns and cognitive processing. This principle is fully within scope and will be implemented through flexible layout systems that can adapt to different content types and user needs while maintaining consistent organizational logic.

Data-Ink Ratio Optimization. The data-ink ratio principle, originally proposed by Tufte [17] and referenced across five studies, emphasizes maximizing the proportion of graphical elements that directly represent data while minimizing decorative or redundant visual elements. This principle appeared consistently in works by Few [15], Yigitbasioglu and Velcu [16], Martins et al.[23], Cepero et al.[48], and implicit in several minimalist design recommendations. The normalization recognized this as a specific application of visual clarity principles, focusing on the mathematical relationship between informational and non-informational graphics. Studies consistently warned against excessive use of colors, decorative 3D elements, and ornamental features that distract from core data interpretation. This principle is within scope and will be implemented through careful selection of chart types, restrained use of visual embellishments, and prioritization of functional over decorative design elements.

Decision Support. Decision support capabilities were explicitly mentioned in five studies as a fundamental purpose of dashboard systems. Few's [15] foundational work emphasized supporting decision-making at a glance, while Matheus et al.[4] highlighted the importance of showing relationships between performance metrics and organizational goals. Maheshwari and Janssen[45] stressed enabling analysis of alternative improvements and scenario analysis, while Ghazisaeidi et al.'s [38] healthcare review emphasized decision-support capabilities through appropriate functional features. The normalization recognized that decision support encompasses both immediate pattern recognition for rapid decisions and deeper analytical capabilities for complex problem-solving. This principle is within scope and will be implemented through clear visual hierarchies, comparative visualizations, and analytical tools that help users identify trends, outliers, and relationships in their data.

User-Centered Design and Audience Consideration. User-centered design principles appeared across five studies, emphasizing the critical importance of aligning dashboard features with user characteristics, needs, and contexts. This normalized principle emerged from Sarikaya et al.'s [21] context-aware design recommendations, Chokki et al.'s [2] audience consideration guidelines, and Martins et al.'s [23] emphasis on user-focused investigation and iterative development processes. Smuts et al.'s [25] focus on novice users and Fan et al.'s [28] accessibility research for older adults highlighted the importance of considering diverse user capabilities and expertise levels. The normalization recognized that effective dashboard design must be grounded in understanding of user roles, decision-making levels, data literacy, and contextual constraints. This principle is within scope and will be addressed through user research, persona development, and iterative testing with target user groups in the public sector.

Contextual Information. The provision of adequate contextual information was emphasized across five studies as essential for proper data interpretation. Vila et al.[8] stressed providing adequate contextual data while avoiding information overload, Chokki et al.[2] highlighted the importance of context and interpretation support, and Cepero et al.[48] emphasized providing sufficient contextual information including baselines and reference lines. Setlur et al.'s[30] conversational framework emphasized context establishment as a foundational stage of analytical dialogue. The normalization recognized that contextual information includes metadata, data provenance, temporal references, and interpretive aids that help users understand not just what the data shows but what it means. This principle is within scope and will be implemented through comprehensive metadata display, explanatory annotations, and contextual help systems.

Accessibility and Usability. Accessibility and usability concerns appeared across five studies, reflecting growing recognition of the importance of inclusive design in dashboard development. Janes et al.[20] specifically warned against using color coding as the only means of conveying information, Fan et al.'s[28] research with older adults provided specific guidelines for improving accessibility, and Ma et al.'s [37] immersive dashboard work emphasized user-friendliness as a core design criterion. Dowding and Merrill's [26] heuristic evaluation framework provided systematic approaches to assessing usability issues. The normalization recognized that accessibility encompasses both compliance with technical standards and broader usability considerations for diverse user populations. This principle is within scope and will be implemented through adherence to web accessibility guidelines, inclusive design practices, and usability testing with diverse user groups.

Customization Options. Customization capabilities were highlighted in five studies as important for accommodating diverse user needs and preferences. Maheshwari and Janssen [45] emphasized allowing metric customization, Matheus et al.[4] stressed supporting customizable views, while Smuts et al.[25] focused on flexible customization processes for novice users. Ma et al.'s [37] immersive dashboard guidelines emphasized flexible and customizable workspaces. The normalization recognized that customization can occur at multiple levels, from simple filtering and view preferences to complex dashboard reconfiguration. This principle is within scope for basic customization features such as filtering, sorting, and view preferences, though advanced customization capabilities requiring significant development resources may be considered for future phases.

Source Transparency and Data Provenance. Transparency regarding data sources and provenance appeared in four studies as crucial for building user trust and enabling informed interpretation. Vila et al.[8] particularly emphasized the importance of clear data provenance for city dashboards, Chokki et al.[2] stressed allowing access to data sources, and Cepero et al.[48] recommended maintaining traceability with references and metadata. Nasir et al.'s[44] information governance framework highlighted transparency and accountability as core principles. The normalization recognized that source transparency encompasses both technical metadata and user-friendly explanations of data collection, processing, and limitations. This principle is within scope and will be implemented through comprehensive metadata systems, source attribution, and data lineage documentation accessible through the dashboard interface.

Minimalist Design and Visual Simplicity. Minimalist design principles appeared in four studies, emphasizing the importance of visual restraint and simplicity in dashboard interfaces. Dowding and Merrill's [26] "aesthetic and minimalist design" heuristic, Cepero et al.'s [48] emphasis on avoiding redundant visual elements, and implicit minimalism in data-ink ratio recommendations all contributed to this normalized principle. Martins et al.'s [23] guidelines for moderate color use and strategic white space utilization further supported this approach. The normalization recognized that minimalist design involves both what to include and what to exclude, requiring careful balance between functionality and simplicity. This principle is within scope and will be implemented through restrained visual hierarchies, limited color palettes, strategic use of white space, and elimination of unnecessary decorative elements.

Perceptual Organization. Perceptual organization principles, primarily based on Gestalt psychology, appeared across four studies. Few's [15] foundational work emphasized applying Gestalt principles for visual organization, Yigitbasioglu and Velcu [16] discussed perceptual optimization in visualization encoding and decoding, and Cepero et al. [48] specifically recommended applying Gestalt principles for strategic grouping of related data elements. The normalization recognized that perceptual organization encompasses both low-level visual grouping principles and higher-level cognitive processing considerations. This principle is within scope and will be implemented through careful attention to visual proximity, similarity, continuity, and closure in dashboard layout and visual design.

Navigation Support. Navigation support appeared in three studies as important for helping users orient themselves and move through dashboard interfaces effectively. Dowding and Merrill's [26] orientation heuristic emphasized navigation controls and context awareness, Smuts et al.[25] highlighted search, filter, and navigation facilities, while Bach et al.'s[22] design patterns included navigation as a key interaction type. The normalization recognized that navigation encompasses both wayfinding within complex dashboards and efficient movement between different views and detail levels. This principle is within scope for basic navigation features, though advanced navigation capabilities may depend on the complexity of the final dashboard implementation.

Error Recovery and Correction. Error recovery capabilities were mentioned in three studies as important for supporting user exploration and building confidence in dashboard interaction. Fan et al.'s [28] research with older adults emphasized supporting trial-and-error exploration and error recovery, Smuts et al.[25] highlighted history tools including undo and redo functionality, and Setlur et al.'s[30] conversational framework included repair and refinement as a critical stage. The normalization recognized that error recovery encompasses both technical undo/redo functionality and broader support for user experimentation and learning. This principle is considered within scope for basic error recovery features, though implementation priority may depend on the complexity of interactive features developed.

Multiple Views and Perspectives. The provision of multiple views or perspectives was emphasized in three studies as important for comprehensive understanding and reducing bias. Matheus et al.[4] explicitly recommended providing multiple views, Smuts et al.[25] highlighted multiple coordinated views for comparison, and implicit support appeared in various drill-down and perspective-switching recommendations. The normalization recognized that multiple views can include both simultaneous display of different visualizations and sequential access to different analytical perspectives on the same data. This principle is within scope and will be implemented through coordinated view systems and flexible visualization options.

Collaboration Features. Collaborative capabilities were mentioned in two studies, though with recognition of growing importance. Ma et al.'s [37] immersive dashboard work emphasized support for seamless collaboration including co-located and remote users, while Smuts et al. [25] included saving, sharing, and collaboration as important features for BI tools. The normalization recognized that collaboration encompasses both real-time collaborative analysis and asynchronous sharing of insights and configurations. This principle is considered outside the current scope due to technical complexity and resource constraints, but may be considered for future development phases as collaboration becomes increasingly important in public sector decision-making processes.

CHAPTER 5

Design and Implementation

5.1 System Architecture and Design

The RTI Dashboard represents a comprehensive web-based platform that enables policy makers to create, configure, and monitor Research, Technology, and Innovation indicators through interactive circular visualizations. The system transforms complex multi-dimensional RTI data into accessible visual interfaces, supporting evidence-based policy evaluation and public transparency through a guided configuration process, flexible data integration capabilities, interactive visualization features, goal-indicator alignment mechanisms, and publicly accessible presentation formats.

The technical architecture, depicted in Figure 5.1, implements a modern three-tier structure optimized for performance and scalability. The frontend layer utilizes Next.js 14 as the foundation for a React-based user interface, integrating the Material-UI component library to ensure consistent and professional visual presentation. This layer implements responsive design principles that provide functionality across various desktop screen sizes, ensuring accessibility for policy makers working in diverse environments. Client-side state management facilitates real-time interactions throughout the interface, providing immediate feedback during user interactions such as data filtering, chart manipulation, and goal-subarea highlighting.

The backend layer uses Spring Boot to deliver a robust RESTful API architecture with comprehensive endpoint coverage supporting all frontend functionality requirements. Authentication and authorization mechanisms implement role-based access control suitable for government deployment, ensuring appropriate security boundaries between administrative and standard user functions. Data processing pipelines handle CSV ingestion and transformation workflows, enabling automatic dimensional mapping and data validation processes. The backend encapsulates business logic for indicator calculations and aggregations, supporting complex analytical operations including multi-dimensional grouping, statistical computations, and goal-indicator relationship management.

The data layer employs PostgreSQL to implement a multi-dimensional data model designed to support multiple unknown dimensions. This includes standard dimensions such as time and location, as well as custom user-defined dimensions like gender, sector, or other categorical variables relevant to RTI analysis. This flexibility is achieved through a custom snowflake schema commonly used in OLAP systems, which enables fast querying and efficient data processing across complex dimensional relationships. The scalable architecture allows users to input, process, and display large datasets without requiring structural modifications, enabling the system to evolve with expanding government RTI monitoring requirements while maintaining optimal performance characteristics.

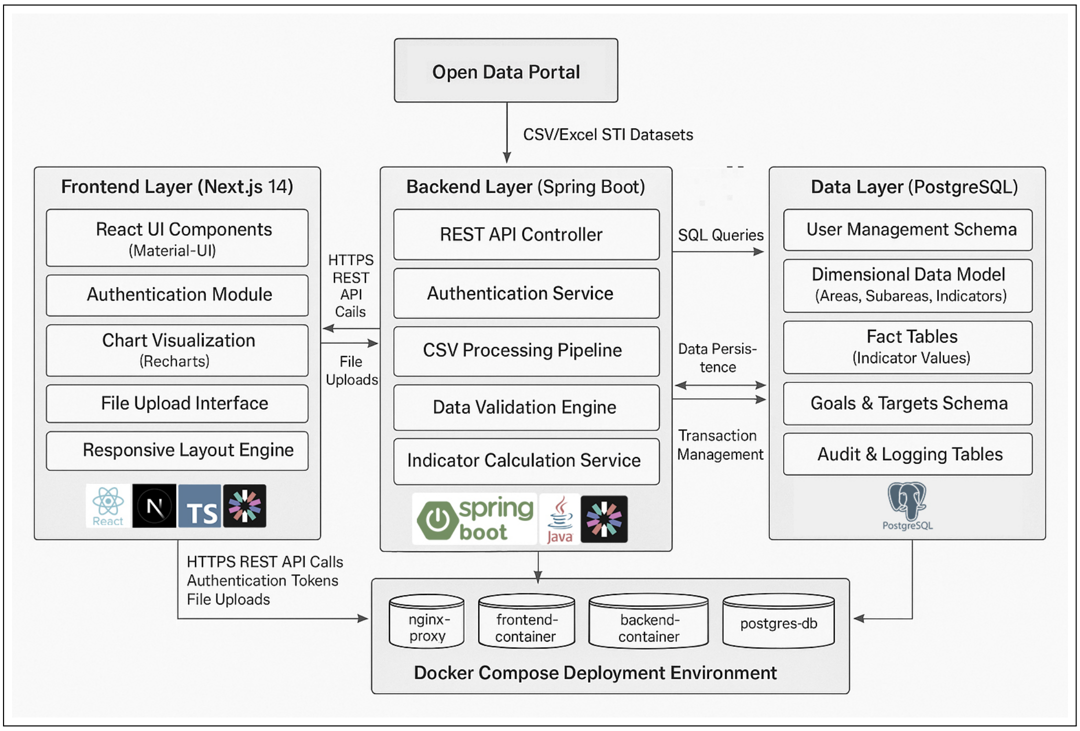


Figure 5.1: System Architecture Diagram showing the three-tier architecture with data flow between components. *This diagram was AI-generated.*

The system utilizes containerized deployment to ensure consistent operation across environments. After download, the entire system can be initiated using a single command `docker-compose up`. This configuration automatically provisions a PostgreSQL database with sample schema, admin account and predefined indicator units, a Spring Boot backend API server, a Next.js frontend application, and an Nginx reverse proxy for production-ready serving. The containerized approach eliminates installation complexity while maintaining professional deployment standards suitable for government environments.

5.2 Configuration Wizard Implementation

The RTI Dashboard implements a guided 5-step configuration process that transforms dashboard setup into an intuitive workflow accessible to non-technical users. This process enables policymakers to establish their monitoring systems without requiring knowledge of backend architecture, database design, or data analytics techniques. The configuration wizard leads users through the following steps: (1) Areas Management, (2) Subareas Management, (3) Data Upload, (4) Indicators Processing, and (5) Goals & Targets. The steps can be seen in Figure 5.2.

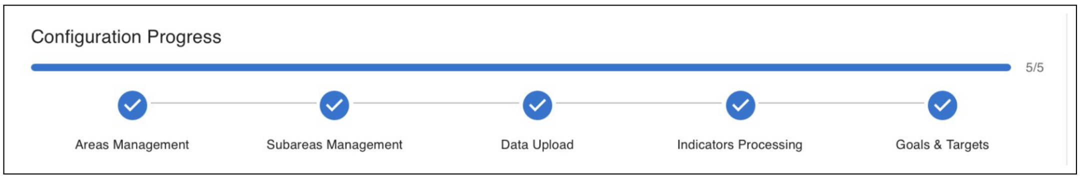


Figure 5.2: Configuration Progress Indicator showing the 5-step progress bar with visual completion status

5.2.1 Areas and Subareas Management

The configuration process initiates with the definition of high-level areas, enabling policymakers to establish the fundamental structure of their monitoring framework. These areas represent broad policy domains subject to monitoring, such as "Regional digitalization" in the provided dataset example. The interface introduces users to dashboard setup through a clean design supported by clear instructions and contextual help. Information presentation occurs in small, manageable units, with the current implementation supporting configuration of up to five areas to maintain interface clarity. Figure 5.3 illustrates this first step of the configuration wizard, where an example area has been created and can be edited or removed, and new areas can be added using the plus button.

Following area definition, the system guides users to establish subareas representing narrower scopes within each area. These subareas contain indicators reflecting the performance of specific policies and can be understood as subdomains or logical units contributing to broader policy objectives. The hierarchical structure between areas and subareas enables the system to model complex policy domains while maintaining conceptual clarity. In the provided dataset, "Companies" and "Households" exemplify subareas, each containing distinct sets of indicators and associated values.

The Subareas Management interface (Figure 5.4) mirrors the design of the previous step, maintaining consistency across the configuration process. It allows users to add, edit, or delete subareas, provide descriptions for contextual clarity, and ensures that each subarea is linked to exactly one parent area. By supporting descriptions alongside names, the system enables policymakers to document the scope and intent of each subarea, thereby improving transparency and interpretability for future users of the dashboard.

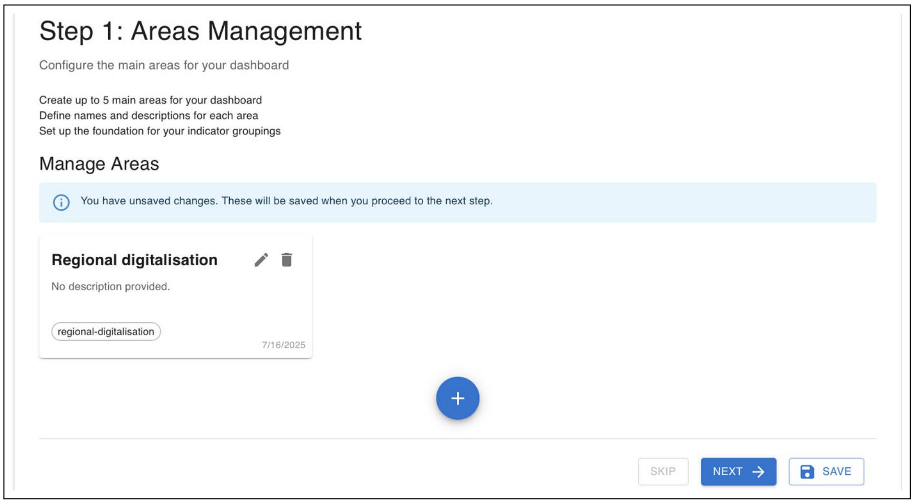


Figure 5.3: Areas Management Interface showing one added area

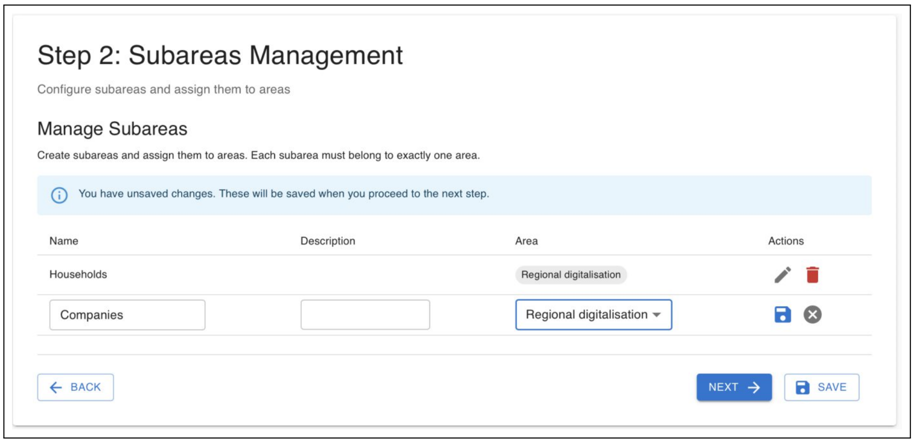


Figure 5.4: Subareas Configuration showing subarea creation and assignment toareas

5.2.2 Data Integration and Processing

The third configuration step focuses on integrating indicator data through a comprehensive upload and mapping interface. Users can import CSV or Excel files and map content to predefined or custom dimensions directly through the interface. Standard dimensions encompass Time, Location, Indicator Name, Indicator Value, Source, and Unit. The system additionally supports Custom Dimensions to reflect specific analytical requirements such as Gender, Sector, or any other dimension relevant to the user's needs or present in the data.

Custom dimension flexibility proves crucial for adapting the dashboard to new policy domains. Since anticipating all potential dimensions arising across different countries, languages, and policy contexts remains impossible, the system allows users to define their own dimensional categories. Gender, age groups, economic sectors, or any other categorical variable relevant to RTI analysis can be added dynamically through the interface, then utilized for filtering and aggregation in the visualization layer.

The system implements a flexible multi-dimensional data model through a custom snowflake schema commonly utilized in OLAP systems. The core architecture consists of dimension tables (`dim_time`, `dim_location`, `dim_generic`) and a central fact table (`fact_indicator_values`) storing indicator values with references to all applicable dimensions. The `dim_generic` table enables users to define custom dimensions without modifying the database schema, supporting extensibility across diverse policy contexts. Each indicator value stores as a tuple containing the indicator reference, dimensional references, and the actual value, enabling efficient querying and aggregation across any combination of dimensions.

From the database schema represented in Figure 5.5, it can be seen that the schema separates the different analytical dimensions into dedicated tables while keeping all numerical values in a central fact table. This design was defined to accept almost any kind of RTI data and was created with flexibility in mind. Standard dimensions such as `dim_time` and `dim_location` provide consistent anchors for comparing indicators across periods and regions, while the inclusion of the `dim_generic` table illustrates how custom categories can be integrated without altering the schema. In this way, every indicator value links to multiple dimensions, making multi-dimensional queries and aggregations straightforward across diverse policy contexts.

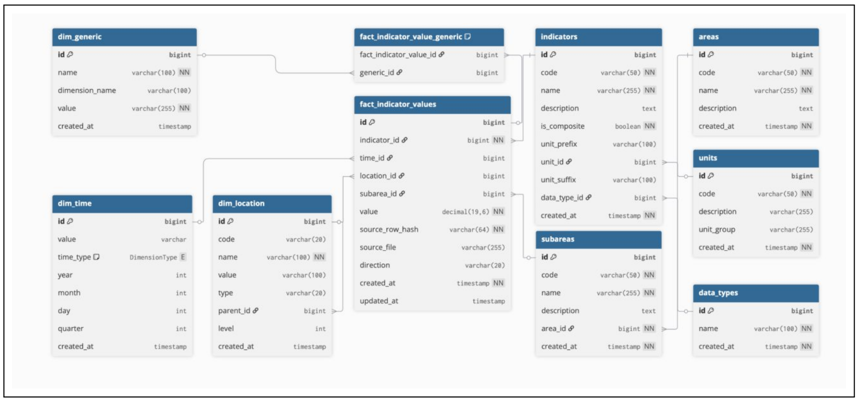


Figure 5.5: Simplified database schema showing the dimensional model supporting flexible indicator storage

To begin the integration process, the dashboard provides a user-friendly upload interface for importing CSV or Excel files (Figure 5.6). The interface supports drag-and-drop functionality as well as manual file browsing, and it allows users to configure technical parameters such as character encoding and delimiters before processing. These options ensure compatibility with diverse datasets and prevent common formatting issues during data ingestion.

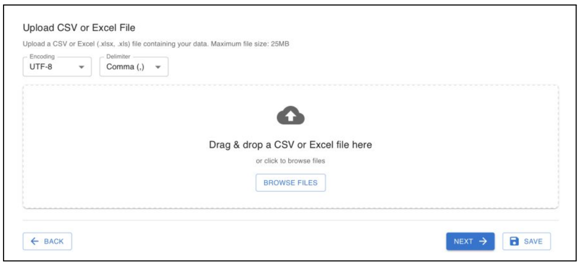


Figure 5.6: CSV Upload Interface showing drag-and-drop file upload

To enhance usability during data preparation, the system provides an interactive, spreadsheet-like mapping interface that supports selection of entire rows, columns, or arbitrary rectangular blocks (Figure 5.7). After a user drags to select cells, a Map Cell Selection dialog appears. In this dialog the user (i) specifies the dimension type—Indicator values, Indicator names, Time (with a subtype such as Year, Month, or Date), Location (e.g., country/state/city), Source, Unit, or an Additional dimension for attributes such as age, sector, or gender; and (ii) sets the mapping direction (by rows or by columns) when appropriate. The interface previews unique values detected in the selection to reduce errors, and the mapping is confirmed with a single action. At least one range must be mapped as Indicator values and at least one as a dimension (e.g., Time or Location) to proceed. Confirmed mappings are transformed into value–dimension tuples in the fact table, enabling flexible aggregation across all defined dimensions. The example shown maps a column block to Time (Year) for Austrian regional data and then continues with Process Mappings.

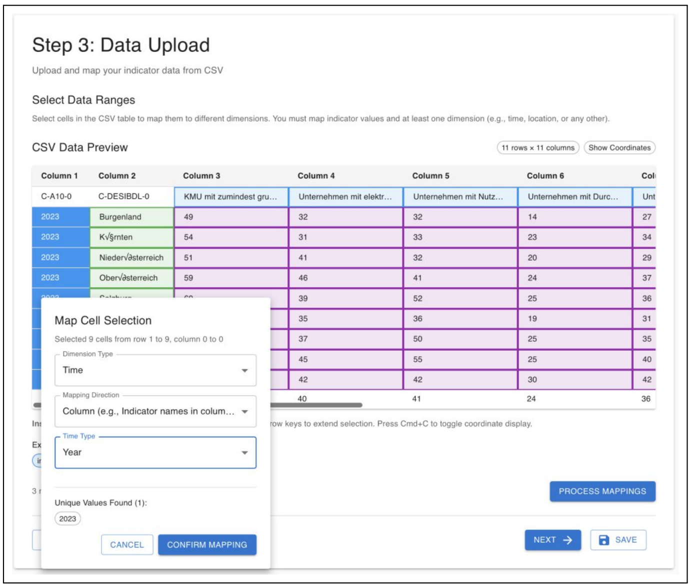


Figure 5.7: Interactive Data Mapping showing the dimensional mapping interface with actual Austrian data

During development and testing with German-language datasets, the system revealed recurring issues with character encoding that extend beyond regional specifics. CSV exports from statistical offices and other data sources often contain inconsistencies, particularly with special characters. To address this, the dashboard integrates an automatic detection and resolution mechanism that scans uploaded files for encoding anomalies, identifies the problematic characters, and suggests replacements.

While initial testing focused on German umlauts (ä, ü, ö), the solution generalizes to any UTF-8 encoding issue. Users can either accept the auto-detected fixes or manually specify alternative replacements for unrecognized sequences. This ensures that indicator data is imported without corruption and that visualizations remain accurate across multilingual and cross-country datasets. Figure 5.8 illustrates the interface, showing a case where three umlaut-related errors were detected and mapped to corrected characters, with the option to apply fixes in bulk or review them individually.

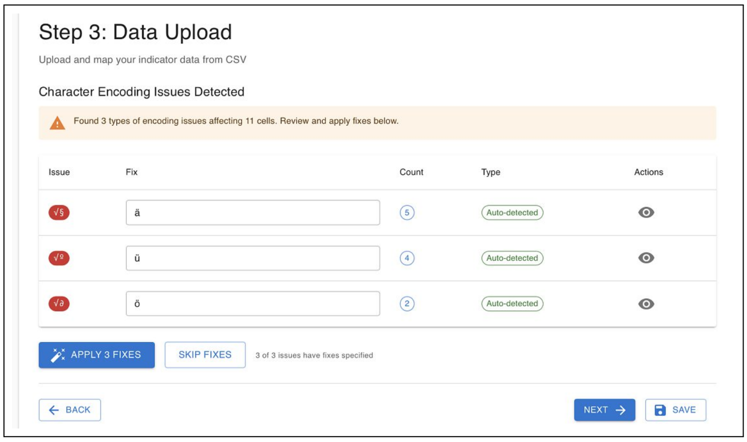


Figure 5.8: Character Encoding Resolution showing automatic detection and fixing of Austrian umlauts (ä, ü, ö)

After mapping completion, each indicator requires assignment to a subarea and specification of its type (input or output), as illustrated in Figure 5.9. This mandatory step ensures that every indicator value is anchored in a relevant subdomain of the monitoring framework, maintaining conceptual clarity and policy relevance. The interface displays the assignment progress, allows indicators to be linked to any subarea defined in earlier steps, and lets users choose whether an indicator functions as an input (e.g., resources, capacities) or an output (e.g., outcomes, results). Importantly, indicators can be reused across different subareas because linking occurs at the value level rather than the name level, supporting flexible analytical perspectives.

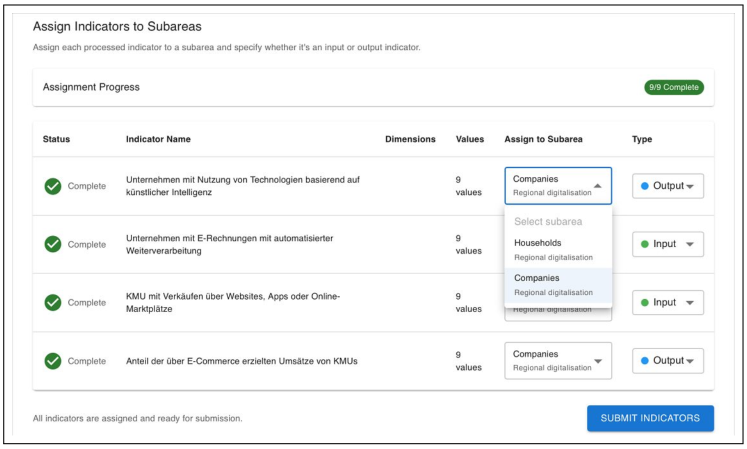


Figure 5.9: Subarea assignment to each indicator

5.2.3 Indicator Management and Goal Alignment

The indicator management interface provides detailed control over metric definition and presentation, serving as the final configuration step before goal alignment. Policymakers can review, revise, and confirm indicators that will later appear in the dashboard. The interface supports editing of names, adding descriptions for contextual clarity, assigning units, specifying data types, and linking indicators to subareas and input/output classifications. It also allows the assignment of source information to ensure traceability. Warnings highlight missing or incomplete fields, such as units, which must be provided for proper visualization and analysis. The table shows currently stored values of indicator dimensions, and by selecting the edit icon (small pencil icon), users can modify all parts of an indicator entry, including even the underlying values themselves. Figure 5.10 illustrates this review process, showing an overview of indicator statistics and the table where individual attributes can be managed.

The system implements validation primarily to ensure data completeness necessary for meaningful aggregation and visualization. Mandatory unit specification enables proper interpretation and aggregation on the frontend, while subarea association requirements maintain the dashboard's circular visualization structure. Though not programmatically enforced at the moment, the system strongly encourages source attribution for transparency. The architecture includes extensible validation structures allowing additional data quality checks in future iterations, though comprehensive validation including range checking, outlier detection, or cross-indicator consistency remains outside current implementation scope.

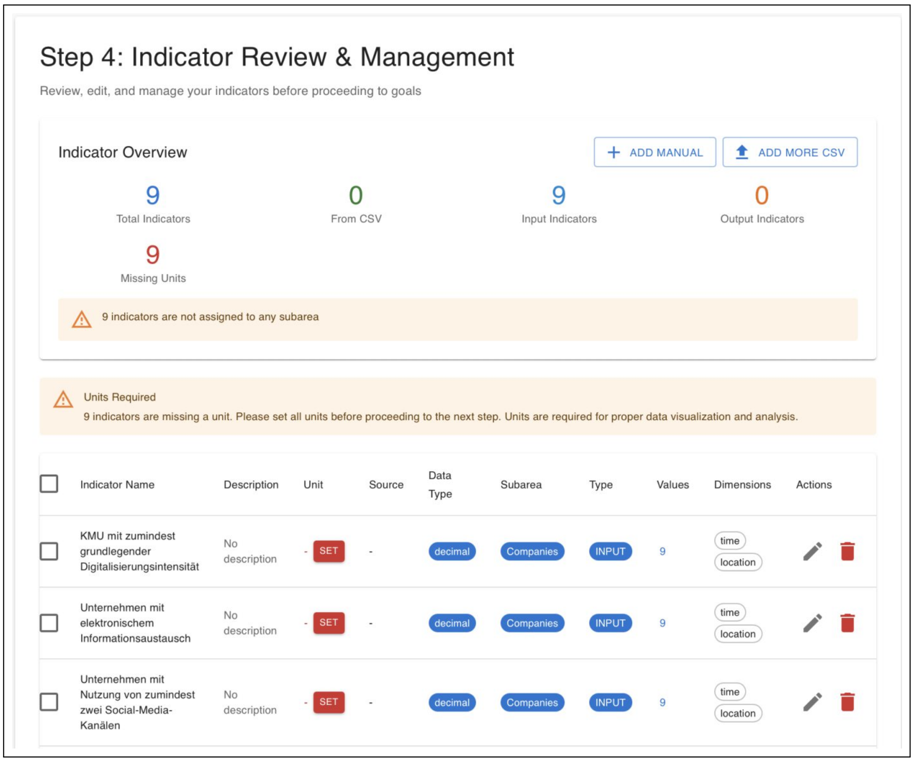


Figure 5.10: Indicator Overview Dashboard showing indicator statistics and management interface

Figure 5.11 depicts the unit picker component, which allows the user to select a unit from a predefined set (expandable as needed) and additionally specify optional prefixes and suffixes. A prefix might indicate the measurement scale (e.g., EUR 1,000), while a suffix can contextualize the indicator (e.g., number of projects or number of companies), ensuring that units are both standardized for aggregation and meaningful for interpretation.

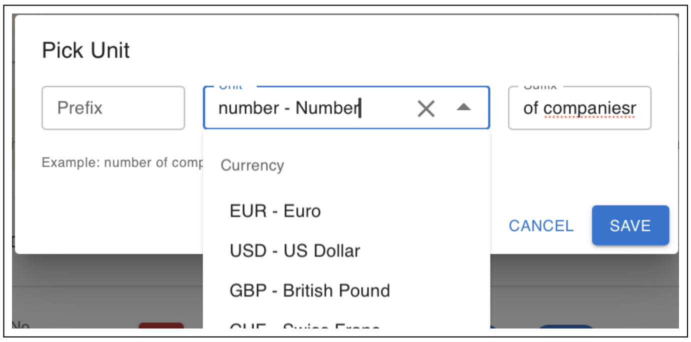


Figure 5.11: Unit Assignment Interface showing the sophisticated unit selection with currency, percentage, and count options

Beyond bulk CSV import, the dashboard supports manual indicator entry to accommodate diverse data sources and emerging information. This functionality addresses integration of data from non-tabular sources without intermediate conversion, addition of individual data points as new statistics become available, and rapid prototyping and testing of indicator configurations before formal data collection. Manual entry maintains the same dimensional structure as CSV import, requiring users to specify all relevant dimensions for each data point, ensuring consistency in the underlying data model while providing flexibility in data input methods. The example in Figure 5.12 illustrates how a user can define an indicator in two steps: first providing metadata (name, description, unit, type, and dimensions), and then entering values across defined dimensions such as location and gender. This ensures that manually entered indicators remain fully compatible with other imported datasets and can be used immediately in the dashboard's visualizations.

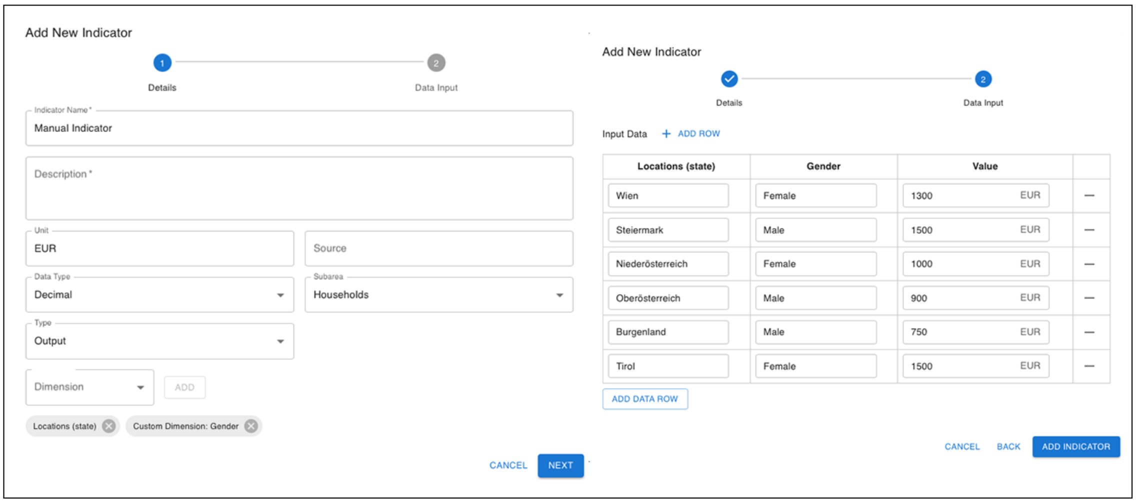


Figure 5.12: Manual indicator input interface

The goal management system operationalizes evidence-based decision-making by linking indicators to concrete objectives and milestones. Goals are organized into configurable groups (e.g., SDGs or local frameworks) and can be created, edited, or removed at any time. The underlying model supports goal hierarchies and many-to-many links between goals and indicators, such that a single indicator may contribute to multiple goals and, conversely, a goal may aggregate evidence from several indicators. Targets can be recorded per goal as dated commitments with an associated value and unit, allowing absolute levels, relative changes, or percentage improvements to be represented. Where indicators move inversely with progress, an impact direction can be specified in the goal–indicator link so that downstream visualizations interpret movement correctly.

Figure 5.13 illustrates the Add Goal dialog. Users specify the goal name, assign it to a Goal Group, set the Year (for the reference or reporting period), and optionally provide a description. The Type field distinguishes quantitative goals from other forms. For quantitative goals, the interface exposes a Targets section where users add one or more target rows, each comprising a Value (numeric stepper), Deadline (date picker), and Unit. The Indicators field (multi-select) links the goal to previously defined indicators; selections appear as chips and can be adjusted at any time. Multiple target rows enable the definition of staged milestones (e.g., interim targets). Selecting Save commits the goal, while Cancel discards changes.

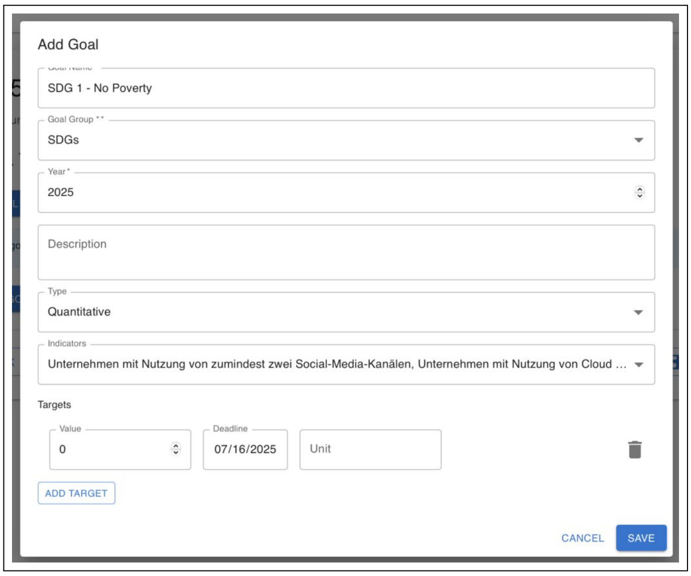


Figure 5.13: Add Goal dialog: users assign group and year, link indicators, and define one or more quantitative targets (value, deadline, unit); multiple rows support staged milestones.

Figure 5.14 presents the Goal Management step, a consolidated view for reviewing goals before completing setup. The list displays all goals within the project (e.g., SDG 1 – No Poverty and SDG 2 – Zero Hunger) with inline actions to edit or delete. The Add Goal button opens the dialog described above; Submit Goals persists the configuration; Save stores the current state without finalizing; and Complete Setup concludes the wizard. This step provides a final integrity check to ensure that all intended objectives have been captured and appropriately linked to indicators.

Full frontend implementation and validation of goal–indicator relationships remain incomplete due to inherent difficulties in establishing clear, quantifiable connections between individual indicators and high-level policy goals. Challenges include heterogeneous aggregation requirements, multi-dimensional calculations, and the absence of standardized goal–indicator mapping methodologies in existing data sources. While these complexities were beyond the immediate project scope, the implemented architecture was deliberately designed to be extendable, ensuring that future enhancements can be integrated without major redevelopment.

Figure 5.14: Goal Management interface showing a review list of goals (e.g., *SDG 1 – No Poverty*, *SDG 2 – Zero Hunger*) with actions to add, edit, delete, submit, or complete setup.

5.3 Interactive Dashboard Interface

Main Dashboard View. The RTI Dashboard's main view adopts a circular layout representing relationships between areas and subareas. This design choice prioritizes clarity and minimizes unnecessary visual elements. The circular arrangement naturally conveys hierarchical relationships without requiring additional connecting lines or decorative elements that might distract from the data itself. This layout can be seen in Figure 5.15.

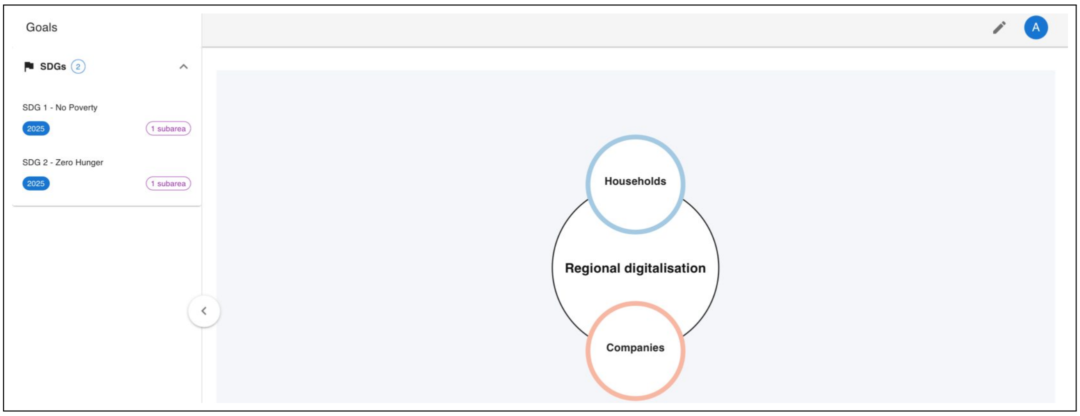


Figure 5.15: Main Dashboard View showing the circular layout with Regional digitalization as the central area and Companies and Households as subareas

The circular layout selection over alternative visualization approaches such as treemaps or hierarchical lists reflects several considerations. The uncluttered design focuses user attention on structural relationships between policy domains. The layout accommodates varying numbers of subareas without visual distortion. Additionally, the backend architecture supports performance-based edge coloring, where subarea borders could indicate goal achievement status, though this feature awaits reliable goal–indicator mapping methodologies.

In this layout, the central area positions at the core with subareas arranged around it. This spatial arrangement makes hierarchical relationships between elements immediately apparent. The layout follows natural reading patterns and guides user attention from central to peripheral components. The design avoids unnecessary decorative elements and maintains a minimalist style. Interactive features such as hover states allow users to explore different components without leaving the main view, offering immediate visual feedback and reinforcing structural clarity.

Goals Sidebar. The goals sidebar integrates strategic policy objectives directly into the dashboard environment. It displays goal groups such as Sustainable Development Goals (SDGs) and allows users to examine individual goals including their target years and associated subareas. When a goal receives hover interaction, the interface highlights relevant subareas, creating dynamic connections between policy targets and operational data. Conversely, hovering over a subarea highlights the goals to which its indicators contribute. These highlights are not arbitrary; they are derived from the goal–indicator relationships defined during Step 5 (Goal Management). For example, hovering over SDG 1 ("No Poverty") or SDG 2 ("Zero Hunger") immediately indicates which subareas link to those goals (see Figure 5.16). This interactive behavior helps users understand how different data parts contribute to higher-level objectives. The sidebar also displays the number of subareas contributing to each goal, demonstrating the dashboard's capacity to handle complex many-to-many relationships between goals and indicators.

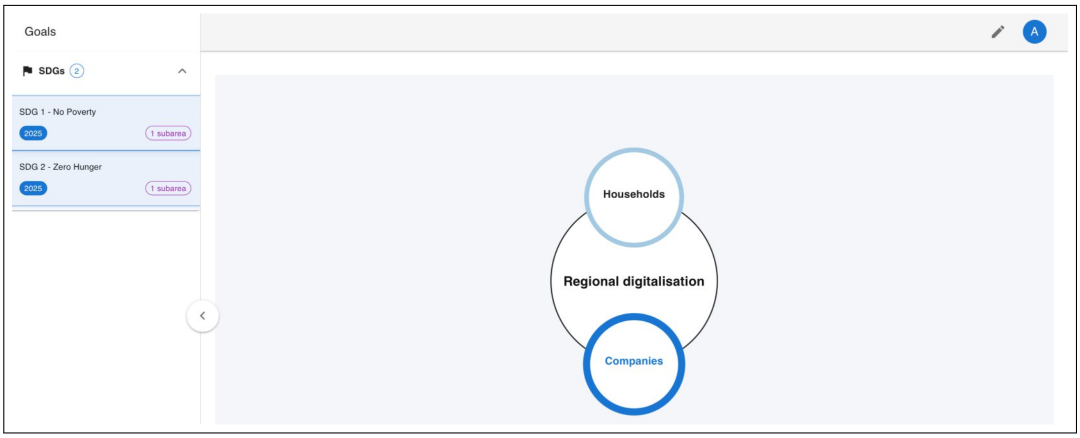


Figure 5.16: Goals Sidebar showing two example goals, each linked to one of the subareas

Subarea Detail View. To support detailed analysis, the dashboard includes drill-down functionality allowing users to explore individual subareas and associated indicators. This hierarchical navigation supports both high-level overview and detailed examination. When selecting a subarea such as "Companies", the system presents a dedicated view containing a time-series visualization and complete indicator list.

The upper section displays a grouped bar chart showing indicator trends over time. This visualization aggregates values for all indicators in the selected subarea, grouped by year, enabling users to assess overall developments and compare indicators visually within the same temporal context.

Beneath the chart, the interface lists all indicators associated with the subarea. Each entry includes the indicator name, its unit, and an icon representing its classification. A filled circle indicates an input indicator, while an outlined circle represents an output indicator. This visual convention provides clear, at-a-glance distinction between different indicator types.

Figure 5.17 shows an example of this view. The subarea "Companies" contains multiple indicators with values for the year 2023. The chart displays these indicator values grouped by year. Below the chart, the first two input indicators (denoted by a filled circle preceding the indicator name) are shown. On the left side, the goals sidebar now lists only the goals associated with the "Companies" subarea.

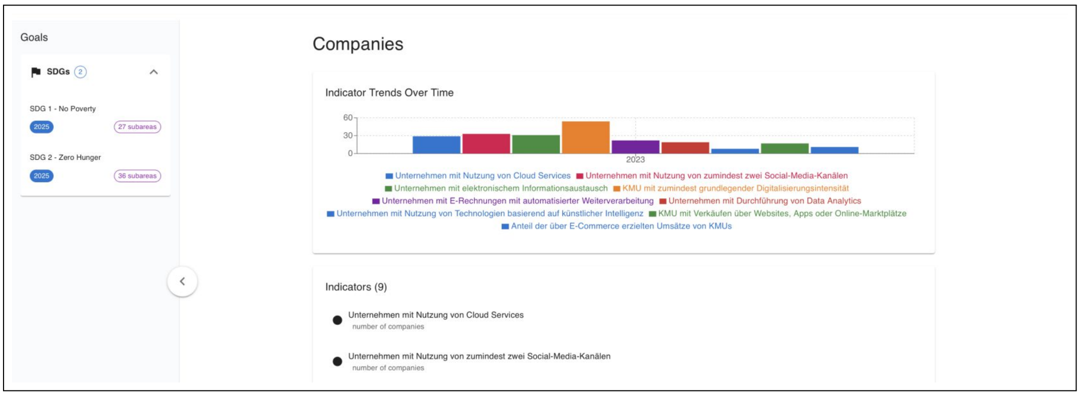


Figure 5.17: Subarea Detail View showing the "Companies" subarea with associated indicator trends and a list of classified indicators

Indicator Modal. Clicking any indicator opens a modal window providing a dedicated interface for indicator-level exploration. This modal supports multiple visualization formats including bar charts, line graphs, and tables. Users can select the dimension by which data should be grouped, such as location or time (Figure 5.18). The flexible visualization options support temporal analysis through line charts for trend identification, comparative analysis through bar charts for cross-regional or cross-category comparisons, and detailed examination through tabular views for precise value inspection.

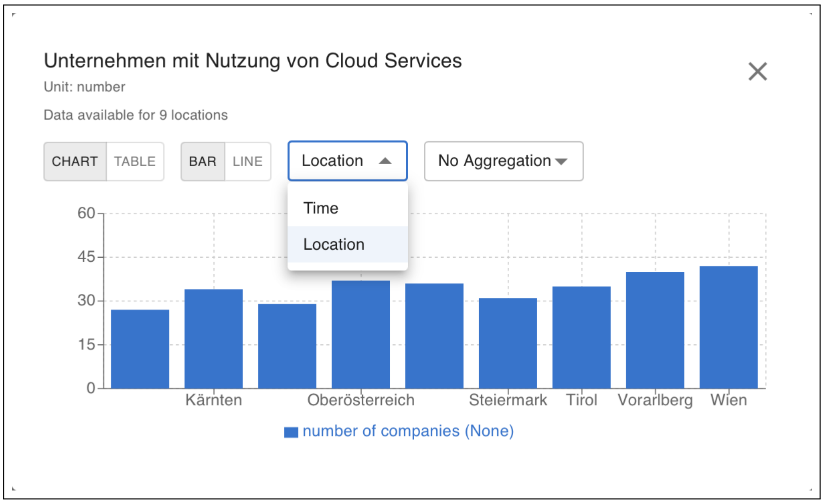


Figure 5.18: Dimension selection menu in the indicator modal, allowing grouping by location or time

If multiple values exist for a given dimension, users can select from several aggregation options including minimum, maximum, count, average, sum, and median. The "No Aggregation" setting displays all raw values grouped by dimension without summarization (Figure 5.19). This flexibility enables users to perform exploratory data analysis and derive insights appropriate to specific policy questions.

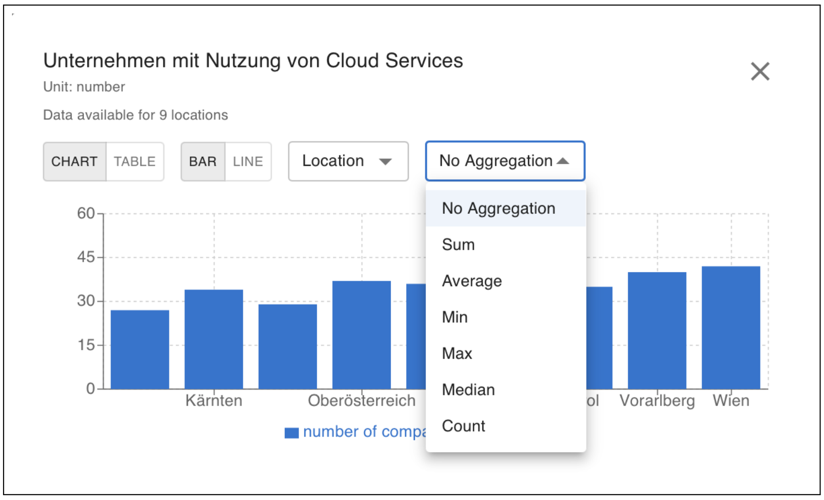
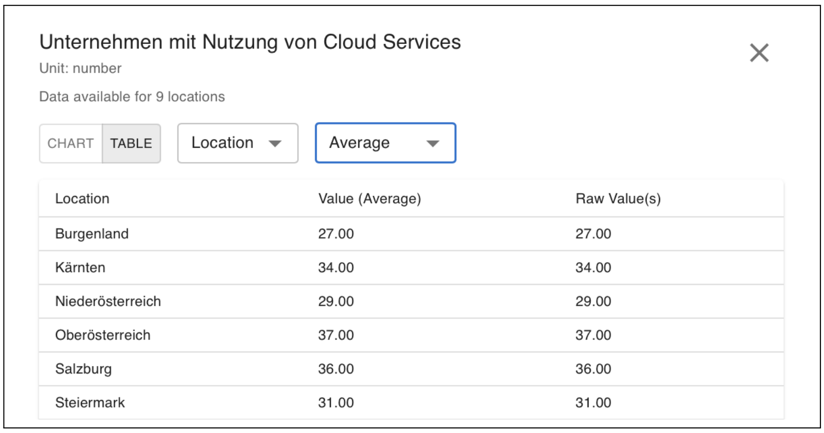


Figure 5.19: Aggregation options available within the indicator modal, including sum, average, min, max, median, and count

The modal features a switch to table view (Figure 5.20), presenting both raw and aggregated values in structured tabular format. This enables detailed data examination and supports external verification or further processing. While the current implementation excludes export functionality, this capability has been identified as a priority for future development to support report generation and data sharing workflows common in policy environments.



Location	Value (Average)	Raw Value(s)
Burgenland	27.00	27.00
Kärnten	34.00	34.00
Niederösterreich	29.00	29.00
Oberösterreich	37.00	37.00
Salzburg	36.00	36.00
Steiermark	31.00	31.00

Figure 5.20: Tabular view showing raw and aggregated values for Austrian federal states for the selected indicator

An example dataset demonstrates how the indicator "Unternehmen mit Nutzung von Cloud Services" distributes across Austria's federal states (Figure 5.21). The data ranges from 27 companies in Burgenland to 42 in Vienna. By switching between visual and tabular modes and applying aggregation and grouping settings, users derive region-specific insights and trends. This detailed, flexible, and context-aware interaction model supports advanced data exploration while preserving the structural clarity of the dashboard interface.

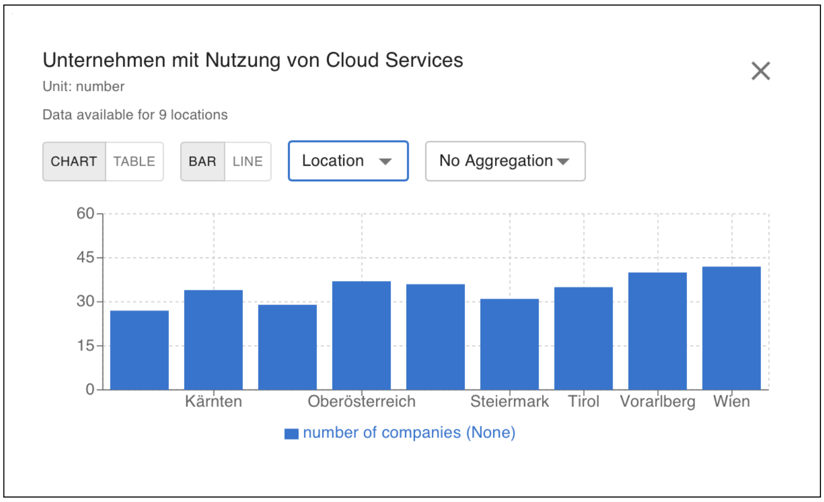


Figure 5.21: Indicator modal showing bar chart grouped by location for cloud service usage

CHAPTER 6

Demonstration and Evaluation

6.1 Demonstration of Design Principles

The implementation of the RTI Dashboard demonstrates the practical application of design principles identified through the systematic literature review. This section evaluates how effectively the developed system addresses each principle, highlighting both successful implementations and areas requiring further development.

6.1.1 Visual Clarity and Data-Ink Ratio Optimization

The dashboard implementation strongly emphasizes visual clarity, addressing one of the most frequently cited principles in the literature. The circular layout visualization (Figure 5.15) exemplifies this principle through its minimalist approach to representing hierarchical relationships. Rather than employing complex network diagrams or cluttered tree structures, the design uses simple geometric shapes and spatial positioning to convey area-subarea relationships. This approach aligns with Few's [15] emphasis on leveraging pre-attentive visual processing, allowing users to immediately grasp the dashboard's organizational structure without conscious effort.

The implementation of data-ink ratio optimization, as advocated by Tufte [17], manifests throughout the interface design. The indicator modal windows (Figures 5.20 and 5.21) demonstrate restraint in visual embellishment, focusing user attention on data rather than decorative elements. Chart borders, gridlines, and axis labels appear only when necessary for data interpretation. The grouped bar chart visualization for subarea indicators (Figure 5.17) uses color sparingly and purposefully, distinguishing between different indicators while avoiding the visual noise that could impair pattern recognition.

However, certain aspects of visual clarity remain underdeveloped. The limitation to five areas, while preventing interface clutter, may prove restrictive for comprehensive national monitoring systems. Additionally, the current implementation lacks visual indicators for data quality or uncertainty, elements that Cepero et al. [48] identify as crucial for transparent data communication in public sector contexts.

6.1.2 User-Centered Design and Accessibility

The 5-step configuration wizard represents a significant achievement in user-centered design, transforming what traditionally requires technical expertise into an accessible process for policy makers. The progressive disclosure approach, evidenced by the step-by-step interface (Figure 5.2), reduces cognitive load by presenting complex configuration tasks in manageable segments. This implementation directly addresses Smuts et al.'s [25] guidelines for supporting novice users through guided development processes.

The spreadsheet-like data mapping interface (Figure 5.7) leverages familiar metaphors to reduce learning curves, a principle emphasized by Dowding and Scherer [26] in their usability heuristics. By mimicking spreadsheet interactions for data selection and mapping, the system builds upon existing user mental models rather than requiring adoption of entirely new interaction paradigms.

The character encoding resolution feature (Figure 5.8) demonstrates attention to real-world usability challenges. While initially developed for German-language datasets, the solution's generalization to any UTF-8 encoding issues reflects consideration for international deployment contexts. This feature addresses practical barriers that could otherwise prevent successful dashboard deployment across diverse linguistic environments.

Nevertheless, the current implementation exhibits limitations in accessibility for users with disabilities. The reliance on hover interactions for goal-subarea highlighting (Figure 5.16) may prove challenging for users with motor impairments. The absence of keyboard navigation alternatives and screen reader optimizations represents a significant gap in achieving comprehensive accessibility, particularly relevant given public sector obligations to ensure universal access.

6.1.3 Data Quality and Transparency

The implementation demonstrates strong commitment to data quality through multiple mechanisms. The mandatory unit specification requirement (Figure 5.11) ensures that all indicators include essential metadata for accurate interpretation. This approach aligns with Ghazisaeidi et al.'s [38] emphasis on comprehensive metrics dictionaries and Vila et al.'s [8] advocacy for transparent metadata provision.

The validation logic implemented in the indicator processing step enforces data completeness while maintaining flexibility for diverse data sources. The support for manual data entry alongside bulk CSV import acknowledges the reality of heterogeneous data sources in government contexts, where critical information may reside in various formats. This flexibility, combined with mandatory validation for core elements, strikes a balance between data quality assurance and practical usability.

Source attribution capabilities, while not programmatically enforced, provide infrastructure for maintaining data provenance—a principle Vila et al. [8] identify as essential for public sector credibility. The system's ability to track and display data sources supports transparency requirements inherent in public administration contexts.

However, the implementation's approach to data quality remains primarily structural rather than substantive. The absence of range checking, outlier detection, or cross-indicator consistency validation represents a significant limitation. While the architecture includes hooks for future enhancement, the current system cannot detect or flag potentially erroneous data values, relying entirely on user vigilance for data accuracy.

6.1.4 Interactivity and Analytical Capabilities

The dashboard's interactive features successfully implement many principles identified in the literature for supporting data exploration and analysis. The drill-down functionality from areas to subareas to individual indicators (Figures 5.15 through 5.21) provides the hierarchical navigation that Yigitbasioglu and Velcu [16] identify as essential for performance dashboards. Users can seamlessly transition from high-level overviews to detailed investigations without losing context.

The dimensional selection and aggregation capabilities (Figures 5.18 and 5.19) demonstrate sophisticated support for varied analytical tasks. By enabling users to group data by different dimensions and apply various aggregation functions, the system accommodates both comparative analysis (spatial tasks) and specific value extraction (symbolic tasks), addressing the cognitive fit principles discussed by Yigitbasioglu and Velcu.

The provision of multiple visualization formats—bar charts, line graphs, and tabular views—within the indicator modal allows users to select representations matching their analytical needs. This flexibility particularly benefits users with varying levels of data literacy, supporting Chokki et al.'s [2] principle of accommodating diverse user capabilities.

The interactive goal-subarea highlighting mechanism (Figure 5.16) represents an innovative approach to connecting strategic objectives with operational data. This feature enables rapid identification of which data elements contribute to specific policy goals, supporting the decision-making alignment that Matheus et al. [4] emphasize as crucial for public sector dashboards.

Yet the implementation falls short of achieving truly conversational interaction as envisioned by Setlur and Hoque [30]. The system lacks mechanisms for users to annotate findings, save analytical states, or share insights with colleagues. The absence of natural language query capabilities or guided analytical suggestions limits the dashboard's ability to support users unfamiliar with data exploration techniques.

6.1.5 Customization and Flexibility

The system demonstrates significant flexibility through its support for custom dimensions, addressing the diverse analytical needs across different policy contexts. The ability to define arbitrary dimensional categories without modifying the underlying database schema (Figure 5.5) provides essential adaptability for international deployment. This architectural decision acknowledges that RTI monitoring requirements vary significantly across jurisdictions, languages, and policy frameworks.

The configuration wizard's approach to areas and subareas definition (Figures 5.3 and 5.4) allows organizations to structure their dashboards according to local policy frameworks rather than imposing rigid categorizations. This flexibility aligns with Maheshwari and Janssen's [45] emphasis on allowing metric customization relevant to specific organizational situations.

However, customization capabilities remain limited in several respects. Users cannot modify the circular layout visualization, adjust color schemes, or save personalized dashboard configurations. The absence of role-based customization means that executives, analysts, and public users encounter identical interfaces despite their vastly different information needs and analytical capabilities.

6.1.6 Decision Support and Goal Alignment

The implementation's approach to goal management represents both significant achievement and notable limitation. The backend infrastructure supporting goal hierarchies, indicator linkages, and temporal target setting (Figures 5.14 through 5.13) provides a robust foundation for decision support functionality. The system's ability to model complex many-to-many relationships between goals and indicators, including negative correlations, demonstrates sophisticated understanding of real-world policy monitoring requirements.

The visual connection between goals and subareas through interactive highlighting offers immediate insight into how operational data relates to strategic objectives. This feature addresses the principle of showing relationships between performance metrics and organizational goals, which Matheus et al. [4] identify as essential for decision support.

Nevertheless, the incomplete frontend implementation of goal-indicator relationships significantly limits the system's decision support capabilities. The inability to visualize progress toward targets, compare actual performance against goals, or aggregate multiple indicators into composite goal measures represents a substantial gap. These limitations stem from the genuine complexity of establishing quantifiable connections between individual indicators and high-level policy objectives, a challenge that extends beyond technical implementation to fundamental questions of policy evaluation.

6.2 Interviews

To evaluate the dashboard prototype in practice, three semi-structured interviews were conducted with participants who had varying degrees of experience with indicators, monitoring systems, and policy evaluation. Each interview was organized around a live demonstration of the dashboard, followed by a series of questions on usability, configurability, and relevance for policy work. The following summaries present the perspectives of the three participants. They highlight aspects that were appreciated, challenges identified, and suggestions for improvement, while keeping the focus on descriptive reporting rather than interpretation.

The **first participant** had extensive experience in monitoring systems, both in developing the FTI monitor and in earlier roles in higher education. They[1] emphasized their focus on communication, usability, and integration of external data sources. When asked about challenges in monitoring systems, they pointed to two recurring issues: the difficulty of presenting data in a way that is intuitive to non-experts, and the persistent problem of data quality and availability. In their words, "The main challenge is presenting data in a way that is intuitive and easy to understand, so that users do not need expert knowledge of Eurostat or other technical terminology."

During the demonstration, the participant confirmed that the setup process was logical and easy to follow, especially since they had seen it before. However, they noted that for first-time users, some terms could be unclear: "For new users, it might help to clarify certain terms, such as "dimension" or "location."" They welcomed the idea of adding tooltips or explanatory screenshots to guide new users. They expressed confidence that policymakers with minimal technical background could configure the dashboard if such aids were implemented.

The participant found the data upload and mapping process to be one of the strongest features, praising its flexibility: "I particularly liked the flexibility in defining dimensions. It allows users to determine how the data will be used later, which makes the system powerful and adaptable." This configurability was described as the most versatile functionality, allowing adaptation to many datasets.

On the visualization side, they judged the design as clear and minimalist, which they appreciated, but also suggested areas for improvement. They felt that dashboards should always include an explicit title or header to establish context: "Although a general header or title would be useful. Without prior context, users might not immediately know what the dashboard is about." They also proposed replacing bar charts with line charts for time-series indicators: "For time-series indicators, I would prefer line charts instead of bar charts." The grouping of areas, sub-areas, and indicators was logical, but the participant cautioned against assuming that "the most important information" can be defined objectively: "What matters is whether users can locate the information they are looking for."

Overall, the participant valued the dashboard's clarity, flexibility, and systemic view, but recommended improving explanatory support, adding contextual cues, and refining visualizations to better serve first-time users and policymakers.

[1]Throughout the interview summaries, the pronoun they is used to refer to participants in order to preserve their anonymity.

The **second participant**, a senior policymaker with extensive experience in indicator work, expressed consistently positive views about the dashboard prototype. They described the setup process as "Yes, it was very clear. The process is simple and guided well, making it easy to understand the steps required to configure a monitor without programming knowledge." They praised the configuration wizard for its logical structure: "Yes, the process is logically structured." The participant stressed that simplicity was a major strength: "Yes, definitely [a policymaker without technical experience could configure the system]."

Regarding the data upload and mapping, they again highlighted clarity and straightforwardness: "Yes, it was straightforward. The guidance made it easy to follow, and I believe it would be clear even without technical support." Importantly, they found that the system not only enabled them to upload data but also helped them better understand the dataset itself, since it forced the user to assign columns and make decisions explicitly.

On first impressions of the dashboard, the participant found it neither overwhelming nor cluttered: "It was not overwhelming. It is simple and clear, although there could be further improvements in visualization." They considered the system especially relevant for policy work, stressing that dashboards can replace traditional printed reports: "Highly relevant. Until now, much of this information was only available in printed reports."

When asked about usefulness, the participant pointed to the ease of selecting and structuring data as the most valuable functionality: "The most useful part is the ease of selecting and uploading data, whether from CSV files or templates." Unlike the first participant, they did not identify any part of the dashboard as unnecessary: "I do not see any part that is not useful — I would not remove any component."

Their main suggestions for improvement concerned the connection between goals and indicators. They proposed strengthening this feature to ensure that goal–indicator mappings are systematic and meaningful: "I would improve the connection between goals and indicators." In addition, they expressed interest in the possibility of annotating or describing outputs within the dashboard: "It would be helpful to allow users to add qualitative descriptions of indicators or outputs." They also recommended that indicators be linked to external databases: "Linking indicators directly to external data sources could also be useful, so that users can easily access original databases."

In sum, the participant strongly endorsed the dashboard's clarity, ease of use, and policy relevance, while calling for more systematic goal alignment and the inclusion of qualitative and provenance-oriented features.

The **third participant** had substantial experience with indicator-based monitoring but less direct experience configuring dashboards themselves. The interview was conducted in German and later translated into English for analysis. The participant described their prior involvement with monitoring primarily through manual work with Excel sheets, which they saw as labor-intensive and often constrained by data timeliness and comparability issues. They appreciated dashboards for their ability to move beyond this mode of work, describing them as “Compared to Excel sheets, this dashboard represents a completely different dimension.”

In terms of setup, the participant found the demonstration clear and understandable: “Yes, it was very clear and well explained.” However, they stressed that they would need narrative guidance or a demo to carry it out independently: “With guided instructions or a demo, yes. Without narrative guidance or feedback, it would be difficult.” They judged the configuration assistant logical and structured: “Yes. The process is logical, structured, and can be learned over time.” But they doubted whether policymakers without prior exposure could configure the dashboard alone, especially under time pressure: “Not without guidance. Policymakers under time pressure and without prior dashboard experience would struggle.”

The participant responded positively to the visualization approach. They considered the design minimalistic, clear, and not overwhelming: “It was not overwhelming. On the contrary, it was minimalistic and reduced to the essentials, which makes it understandable and low-threshold.” They valued the dashboard for presentations and communication purposes, noting that interactivity adds considerable value compared to static reports. At the same time, they stressed that data provenance must always be visible: “Although information on data sources was not always visible in the final visualization. Data provenance is important, so the source of each indicator should be consistently displayed.” They also raised the issue of versioning: “It is important that there is something like a download, where you say, okay, this is the status now.”

On the grouping of areas, sub-areas, and indicators, the participant agreed that the structure was logical and connected to data availability: “Yes. The grouping follows a logical structure based on data availability.” They also found it interesting when indicators appeared multiple times across categories, seeing potential for building links or bridges in such cases. They confirmed the relevance of dashboards for political work: “Very relevant. Tools such as the FTI Monitor have already set a precedent, and dashboards are becoming increasingly important in political work.”

In terms of usefulness, the participant highlighted the overall overview as the most important element: “The overall overview is the most useful, as it provides a broad picture before focusing on details.” They did not consider any component redundant but stressed that user support is essential: “The most important improvement would be to provide more explanatory support, such as info boxes, tooltips, or digital help.” Finally, they suggested onboarding showcases: “Small demos or showcases would also be very useful, guiding users through the setup or dashboard functions step by step.”

Overall, the third participant appreciated the clarity, minimalism, and communicative potential of the dashboard, while highlighting the importance of provenance, versioning, and explanatory support to make it fully usable in real-world policy contexts.

In summary, the demonstration and interviews provided practical insights into the usability, configurability, and relevance of the dashboard, setting the stage for the concluding discussion where these findings are synthesized and evaluated against the design principles identified in the literature.

CHAPTER 7

Conclusion

This thesis set out to develop and evaluate a modular dashboard for Research, Technology, and Innovation (RTI) policy evaluation in the public sector. Guided by a systematic literature review, a set of design principles was consolidated from prior research and used to inform the development of the prototype. The system was then implemented and assessed through both demonstration against the literature-derived principles and semi-structured interviews with three domain experts. The results highlight both the feasibility of operationalizing design principles in practice and the challenges of adapting them to real-world contexts.

The RTI Dashboard implementation successfully demonstrates the feasibility of translating academic design principles into a functional system for public sector use. The configuration wizard's transformation of complex technical processes into accessible workflows represents a particularly notable achievement, as does the flexible dimensional architecture supporting diverse analytical contexts. The system's emphasis on visual clarity, hierarchical navigation, and interactive exploration aligns well with established dashboard design principles such as those proposed by Few [15], Tufte [17], and Yigitbasioglu and Velcu [16]. The architecture, based on a scalable three-tier system with a flexible snowflake schema, provides a strong technical foundation for handling diverse datasets and supporting future extensions.

At the same time, several significant gaps remain between theoretical principles and practical implementation. The absence of comprehensive accessibility features, limited customization options, and incomplete goal-tracking functionality highlight the challenges of fully realizing academic design recommendations within project constraints. The literature strongly emphasizes accessibility, provenance, and decision support [48, 4], yet these areas remain only partially addressed in the current system. This confirms that while visual and interaction design principles can often be implemented directly, principles involving advanced analytics, accessibility, and organizational alignment require substantially greater development effort and institutional support.

The interviews provided critical empirical insights that complement the design-based evaluation. The first participant highlighted configurability and clarity as central strengths, praising the flexibility of the data mapping interface and the systemic representation achieved by the circular layout. Their suggestions emphasized improving contextual support, such as tooltips and clear titles, and refining visualization choices for time series. The second participant expressed strongly positive views of the prototype, underscoring its relevance for replacing static reports in policymaking and its accessibility for non-technical users. Their recommendations focused on strengthening goal–indicator linkages, allowing for qualitative annotation, and linking directly to external data sources. The third participant valued the dashboard's clarity and minimalism, describing it as "a completely different dimension compared to Excel," but stressed the need for explanatory support and provenance. They emphasized that policymakers under time pressure would struggle without clear guidance and recommended export and versioning features to ensure traceability of results.

Taken together, these perspectives reveal strong consensus on the value of clarity, configurability, and systemic representation, but also consistent recognition of missing elements that are critical for real-world adoption. All three participants stressed that explanatory support—through tooltips, guides, or demo showcases—would be essential to make the system usable by non-specialists. Two participants highlighted the importance of provenance and source visibility, aligning with Vila et al.'s [8] emphasis on transparency. Two also called for improved connection between goals and indicators, confirming the literature's view that decision support remains a difficult but crucial feature for public sector dashboards [4]. These overlaps show where future developments should be directed.

From a methodological perspective, the study demonstrates the usefulness of combining literature-driven design with empirical evaluation. The systematic review identified a broad set of principles—visual clarity, interactivity, contextual information, accessibility, provenance, and decision support—that formed the blueprint for implementation. The demonstration confirmed that many of these could be operationalized, particularly those related to visualization and interaction. The interviews then provided a reality check, highlighting where abstract design principles intersect with the practical constraints and expectations of policymakers. This dual perspective strengthens the validity of the findings and provides a roadmap for prioritizing future development.

In terms of contributions, this thesis makes both academic and practical advances. Academically, it synthesizes 25 studies into a consolidated set of dashboard design principles, demonstrating their applicability to the public sector and identifying where theory aligns with practice. It also contributes empirical evidence on how domain experts perceive these principles when instantiated in a working prototype. Practically, the thesis delivers a functioning modular dashboard system that can be deployed with minimal setup, providing policymakers with a flexible and extensible tool for indicator monitoring. The configuration wizard, dimensional architecture, and interactive visualizations represent tangible outputs that can inform both policy practice and future research projects.

In conclusion, the prototype confirms the feasibility and value of a modular, configurable dashboard for RTI policy evaluation. It operationalizes key academic principles such as visual clarity, interactivity, and configurability, while also revealing the limitations that arise from technical, organizational, and contextual constraints. The findings suggest that future work should prioritize accessibility, user guidance, provenance, and decision support, as these emerged consistently across both literature and interviews. Addressing these areas would transform the dashboard from a promising prototype into a robust policy support tool capable of meeting the diverse needs of policymakers, analysts, and stakeholders in the public sector.

Appendix

Consolidated Design Principles from the Literature

This appendix presents the full set of dashboard design principles identified in the literature review, organized by source (see Table 1). The consolidated checklist provides the basis for evaluating our dashboard prototypes and serves two main functions:

- It establishes a traceable link between each evaluation criterion and peer-reviewed sources.
- It enables systematic comparison between the prototypes and established best practices.

Table 1: Mapping of Original and Normalized Design Principles in Dashboard Literature

Ref	Original Design Principles	Normalized Design Principles
[15]	• Simplicity and clarity • Reduce non-data pixels • Enhance data pixels • Apply Gestalt principles • Organize content meaningfully • Support decision-making at a glance	• Visual Clarity • Data-Ink Ratio Optimization • Perceptual Organization • Content Organization • Decision Support
[16]	• Balance functional and visual features • Encoding and decoding process in visualization • Maximize data-ink ratio • Use gridlines as visual aids • Single screen overview with drill-down capabilities • Avoid unnecessary features • Align with users' cognitive characteristics • Provide both graphical and tabular representations	• Functional-Visual Balance • Perceptual Optimization • Data-Ink Ratio Optimization • Visual Aids • Information Hierarchy • Minimalist Design • Cognitive Alignment • Representation Flexibility
[20]	• Enable effortless access • Make interaction optional • Organize content for quick interpretation • Direct focus toward critical information • Display elements in visually appealing ways • Consider accessible design	• Accessibility • Optional Interactivity • Content Organization • Attention Guidance • Visual Appeal • Inclusive Design

[45]	• Allow metric customization • Use available data resources and prioritize key metrics • Link dashboard elements to performance metrics • Enable analysis of alternatives • Instant visual communication • Multi-level design • Support with data comprehension • Continuous improvement and development	• Metric Customization • Data Resource Optimization • Performance Alignment • Scenario Analysis • Visual Communication • Multi-level Design • Comprehension Support • Continuous Improvement
[25]	• Easy development process • Guided development process • Flexible customization process • Immediate and interactive visual feedback • User friendly data input • Automatic visualizations with defaults • Search, filter, and navigation facilities • Multiple coordinated views for comparison • History tools and storytelling (undo/redo) • Promote learning through explanations • Saving, sharing and collaboration	• Development Simplicity • Guided Process • Customization Flexibility • Interactive Feedback • Data Input Usability • Automated Visualization • Navigation Support • View Coordination • Reversibility • Educational Support • Collaboration Features
[38]	• Performance Measures (PMs) and KPIs Development • Data Sources and Data Quality • Integration of Dashboards with Source Systems • Information Presentation (align with cognitive tasks)	• KPI Development • Data Quality Management • System Integration • Cognitive-Aligned Presentation

[26]	• Visibility of system status • Match between system and real world • User control and freedom • Consistency and standards • Recognition rather than recall • Flexibility and efficiency of use • Aesthetic and minimalist design • Spatial organization • Information coding • Orientation	• System Feedback • Real-World Correspondence • User Control • Consistency • Recognition Support • Efficiency • Minimalist Design • Spatial Organization • Information Encoding • Navigation Support
[8]	• View all relevant information on a single screen • Provide adequate contextual data • Avoid information overload • Match visualization to data characteristics • Arrange dashboard elements strategically • Provide clear data provenance	• Single-Screen View • Contextual Information • Information Balance • Visualization-Data Matching • Strategic Layout • Data Provenance
[46]	• Action-worthy indicators • Actionable indicators • Behavioral indicators • Valid indicators • Reliable indicators	• Relevance • Actionability • Implementation Focus • Validity • Reliability
[21]	• Context-aware design principles • Align with user roles and decision-making levels • Consider visualization literacy	• Contextual Alignment • User Role Adaptation • Literacy Consideration
[4]	• Ensure data is accurate and precise • Support customizable views • Provide multiple views • Present data clearly • Support decision-making • Support interactive features • Incorporate drill-down functionality • Promote public values • Strive for real-time data updates • Ensure institutional support	• Data Quality • View Customization • Multiple Perspectives • Clear Presentation • Decision Support • Interactivity • Hierarchical Exploration • Public Value Alignment • Data Currency • Institutional Backing

[37]	• Accurate and expressive data presentation • Direct and consistent interaction • Compact and intuitive layout • Flexible and customizable workspace • Support for seamless collaboration • Accessibility and user-friendliness	• Data Accuracy • Interaction Consistency • Layout Compactness • Workspace Flexibility • Collaboration Support • Accessibility
[2]	• Collect accurate and precise data • Ensure data consistency • Consider audience • Use best visualization practices • Use the right types of charts • Provide easy-to-use tools • Clear presentation • Provide context and interpretation support • Consider data literacy levels • Ensure data is up to date • Allow access to data source • Check for personal data/outliers • Interaction support • Ensure feedback support • Enable customization	• Data Accuracy • Data Consistency • Audience Consideration • Visualization Best Practices • Chart Selection • Tool Usability • Clear Presentation • Interpretation Support • Literacy Consideration • Data Currency • Source Transparency • Privacy Protection • Interactive Features • Feedback Mechanisms • Customization Options
[47]	• Dashboards as facilitative infrastructures for dialogue • Support reflexivity and learning • Support co-production of knowledge • Adapt to governance model complexity	• Dialogue Facilitation • Reflexivity Support • Knowledge Co-production • Governance Alignment
[36]	• Visual Attention Feedback (VAF) • Adaptive interfaces to manage cognitive load	• Attention Management • Cognitive Load Optimization
[27]	• Task Performance • Behaviour Change • Interaction Workflow • Perceived Engagement • Potential Utility • Algorithm Performance • System Implementation	• Task Support • Behavior Influence • Workflow Optimization • User Engagement • Adaptability • Algorithmic Quality • Implementation Practicality

[22]	• Content Design Patterns (data abstraction, meta-information, visual representations) • Composition Design Patterns (layout, screenspace management, structural relationships, interaction types, color schemes) • Balance information abstraction, screen space, number of pages, and degree of interaction	• Content Pattern Application • Composition Pattern Application • Design Tradeoff Management
[23]	• Interface design (page organization, color, typography) • Use grid system for organization • Include blank spaces in layout • Use color moderately • Prioritize typography readability • Use tables for data comparison • User-centered design process • Begin with user-focused investigation • Iterative UI design process	• Interface Organization • Grid-Based Layout • White Space Utilization • Color Moderation • Typography Optimization • Appropriate Visualization • User-Centered Design • User Research Priority • Iterative Development
[33]	• Enable natural language interaction • Support mixed-mode interaction • Integrate conversational onboarding mechanisms	• Natural Language Support • Multimodal Interaction • Conversational Guidance
[28]	• Increase legibility of visual designs • Facilitate understanding of affordances • Match with user expectations • Support trial-and-error and error recovery • Ensure intuitive interaction	• Visual Legibility • Affordance Clarity • User Expectation Alignment • Error Recovery • Intuitive Interaction
[3]	• Stakeholder-specific roles and indicators • Field and organization-specific metrics • Support for comparative analyses • Semi-centralized organizational approach • Alignment with organizational missions	• Stakeholder Alignment • Contextual Metrics • Comparative Analysis • Governance Structure • Mission Alignment

[9]	• View topic, factors, and values at a glance • Show spatial information at different granularities • Support visual reasoning • Support interactivity • Ensure ease of use	• Information Overview • Spatial Context • Visual Reasoning Support • Interactive Features • Usability Focus
[30]	• Initiation (provide information and explanations) • Grounding (build shared understanding) • Turn-taking (bi-directional communication) • Repair and refinement (verify understanding) • Close (share insights)	• Onboarding Support • Context Establishment • Interaction Dialogue • Error Correction • Insight Sharing
[48]	• Match visualization methods to analytical purposes • Clearly label visualizations • Maintain traceability with references/metadata • Provide contextual information • Avoid redundant visual elements • Maximize data-ink ratio • Apply Gestalt principles	• Purpose-Aligned Visualization • Clear Labeling • Source Transparency • Contextual Information • Visual Simplicity • Data-Ink Ratio Optimization • Perceptual Organization
[44]	• Information governance integration (Quality, Security, Compliance, Integrity, Availability, Transparency, Accountability, Effectiveness)	• Information Governance • Data Quality Management • Security and Compliance • Integrity and Transparency • Accountability • Effectiveness

Interview Questions

These questions were used as guidelines for the dashboard evaluation interviews. Participants were encouraged to answer freely and elaborate where they felt it was important. When a participant's answer addressed multiple questions at once, the overlapping questions were skipped. In other words, not all questions needed to be answered individually.

1. What is your role and experience with data dashboards?
2. How familiar are you with RTI indicators?
3. What challenges have you faced with existing monitoring systems?
4. Was the setup process clear to follow as I walked through it?
5. Would you feel confident doing the setup process yourself?
6. Were the steps in the configuration wizard logically structured and understandable?
7. Do you think a policymaker without technical experience could configure this dashboard?
8. Was the data upload and mapping process understandable from what you saw?
9. How would you describe your first impression of the dashboard?
10. Is the dashboard visually appealing or overwhelming?
11. Was it clear what kind of data the dashboard is showing?
12. Did the grouping of areas, subareas/subdomains, and indicators make sense to you?
13. Would you be able to quickly locate the most important information?
14. How relevant is this kind of dashboard for policy work in your field?
15. Would you find this helpful for identifying problems or tracking progress?
16. Which parts of the dashboard seemed most useful? Least useful?
17. Could you read all the text and understand all chart elements?
18. Did the use of color, layout, and labels support your understanding?
19. Were there any elements that were confusing or hard to interpret?
20. What is one thing you would improve about the dashboard?
21. Is there anything missing that you would expect to be included?

Interview Transcripts

The following transcripts are cleaned for readability. Filler words and irrelevant small talk were removed, while all substantive responses were preserved. This is consistent with the methodological approach described in Section 3.

Interview Transcript: Participant 1

Background and Role

Q: What is your role and experience with data dashboards? **A:** I joined the council with a colleague, and together we worked on creating what is now the FTI monitor. We defined its scope, target audience, and design. My focus has been on communicating information, usability, and integrating additional data sources. For instance, we connected the monitor with the R&D Investments Core Board and explored links with green technology dashboards. Each year, we review the indicators to determine whether they remain valuable, legitimate, and relevant. We also add new functionalities in collaboration with external partners. Before this role, I worked at the University of Vienna as head of the Student Service Center, where I oversaw tracking systems to help students understand the consequences of their study program choices. This project was later scaled to other universities.

Q: How familiar are you with RTI indicators? **A:** I have direct experience with RTI indicators, particularly through the procurement and maintenance of indicators within the FTI monitor. This includes both selection and communication of the indicators.

Q: What challenges have you faced with existing monitoring systems? **A:** The main challenge is presenting data in a way that is intuitive and easy to understand, so that users do not need expert knowledge of Eurostat or other technical terminology. A second recurring challenge is data quality and availability.

Evaluation of the Dashboard Prototype

Q: Was the setup process clear to follow as it was demonstrated?
A: Yes. Since I had seen it before, it was clear to me. For new users, it might help to clarify certain terms, such as “dimension” or “location.”

Q: Would you feel confident doing the setup process yourself?
A: Yes, I would. With small guidelines or tooltips explaining terms, non-technical users should also be able to configure it.

Q: Was the data upload and mapping process understandable?
A: Yes. I particularly liked the flexibility in defining dimensions. It allows users to determine how the data will be used later, which makes the system powerful and adaptable.

Q: What was your first impression of the dashboard view?
A: The circular layout makes sense for showing how areas and sub-areas interact as part of a system. It reflects the interconnections between different policy areas, which is valuable.

Q: Was the dashboard overwhelming, or did it feel manageable?
A: It was not overwhelming. The minimalist design principle is evident.

Q: Was it clear what kind of data the dashboard is showing?
A: Yes, although a general header or title would be useful. Without prior context, users might not immediately know what the dashboard is about.

Q: Did the grouping of areas, sub-areas, and indicators make sense?
A: Yes. The only caveat is that "most important information" is subjective. What matters is whether users can locate the information they are looking for. The inclusion of an indicator search function is a good solution for this.

Q: Would the dashboard be useful for tracking progress and identifying problems?
A: Yes, it would.

Q: Which parts of the dashboard seem most or least useful?
A: It is difficult to separate parts, since they depend on one another. The configuration wizard is especially versatile, as it allows adaptation to many different datasets.

Q: Could you read all text and understand the chart elements?
A: Yes. The only unclear element was the color of the rings, which seemed random without the goals connection. Once explained, this made sense.

Q: Were there any confusing or hard-to-interpret elements?
A: Some pop-up windows contained long texts that were slightly overwhelming, but this depends strongly on the dataset.

Q: What is one thing you would improve about the dashboard?
A: For time-series indicators, I would prefer line charts instead of bar charts. They are easier to interpret at a glance, especially with longer time spans.

Q: Is there anything missing that you would expect?
A: From this brief demonstration, nothing essential seems missing. The visuals could be more elaborate, but that may be beyond the current scope.

Summary. The participant emphasized the importance of intuitive design, data quality, and clear terminology. The configuration wizard was highlighted as particularly useful and versatile. Suggested improvements included adding explanatory tooltips, a general header for context, and the option to display time-series data as line charts.

Interview Transcript: Participant 2

Background and Role

Q: What is your role and experience with data dashboards?
A: I am the Deputy Managing Director of the Austrian Council (FORWIT). I have experience with RTI indicators in the Austrian RTI system, particularly through collaboration with WIFO on monitoring tools such as the RTI Monitor. I am moderately familiar with indicators and their use in comparing Austria with other countries.

Q: How familiar are you with RTI indicators?
A: I am reasonably familiar, mainly through working with indicators in performance monitoring and international comparisons.

Q: What challenges have you faced with existing monitoring systems?
A: Most dashboards are too complex and not user-friendly. They often lack a systemic overview that shows how indicators are connected. Many dashboards are siloed — each one covers a single topic, but they do not provide a comprehensive view. Additionally, for those without technical expertise, building such a monitor is difficult.

Evaluation of the Dashboard Prototype

Q: Was the setup process clear to follow as it was demonstrated?
A: Yes, it was very clear. The process is simple and guided well, making it easy to understand the steps required to configure a monitor without programming knowledge.

Q: Were the steps logically structured?
A: Yes, the process is logically structured.

Q: Could a policymaker without technical experience configure the system?
A: Yes, definitely.

Q: Was the data upload and mapping process understandable?
A: Yes, it was straightforward. The guidance made it easy to follow, and I believe it would be clear even without technical support.

Q: What was your first impression of the dashboard interface? Was it visually appealing or overwhelming?
A: It was not overwhelming. It is simple and clear, although there could be further improvements in visualization. For a first impression, however, it is sufficient and not overloaded like many other dashboards.

Q: Was it clear what kind of data the dashboard is showing?
A: Yes. It is easy to understand which data have been uploaded and how they are visualized.

Q: Would you be able to quickly locate the most important information?
A: Yes, provided I am familiar with the dataset. If I created the Excel file myself, it is easy. If I receive a dataset from someone else, it may take more time. However,

the dashboard helps by clarifying the structure of the dataset and forcing me to define columns during the setup process, which improves understanding.

Q: How relevant are dashboards of this kind for policy work in your field?
A: Highly relevant. Until now, much of this information was only available in printed reports. Such tools are essential for advancing digital transformation and making monitoring more interactive and useful.

Q: Would this dashboard help identify problems or track progress?
A: Yes. By linking indicators to goals or strategies, it provides a systemic view and supports performance evaluation.

Q: Which parts of the dashboard seem most useful, and which least useful?
A: The most useful part is the ease of selecting and uploading data, whether from CSV files or templates. The fact that it supports both visual overviews and time series analysis is valuable. I do not see any part that is not useful — I would not remove any component.

Q: Could you read all text and understand all chart elements?
A: Yes.

Q: Did the use of color, layout, and labels support understanding?
A: Yes. Color choices may need to be refined in cooperation with domain experts, as preferences vary depending on the data and user group. For now, they are sufficient.

Q: What is one thing you would improve about the dashboard?
A: I would improve the connection between goals and indicators. Specifically, the mapping between indicators and goals could be expanded to provide a clearer overview of how performance is linked to strategic objectives.

Q: Is there anything missing that you would expect to be included?
A: It would be helpful to allow users to add qualitative descriptions of indicators or outputs. Linking indicators directly to external data sources could also be useful, so that users can easily access original databases.

Summary The participant found the setup process intuitive and the structure clear, emphasizing the importance of ease of use for non-technical policymakers. The dashboard was judged highly relevant for policy work, especially as a step beyond static printed reports. Key strengths include the data upload process, clarity of structure, and systemic view enabled by goal-indicator connections. Suggested improvements included stronger visualization, enhanced goal mapping, the ability to add qualitative descriptions, and links to original data sources.

Interview Transcript: Participant 3

Background and Role

Q: What is your role and experience with data dashboards?
A: I am familiar with data dashboards primarily through my involvement in the Research

and Technology Report, where selected FTI indicators are presented over time, as well as in comparative analyses such as the European Innovation Scoreboard. My role has been more observational and descriptive rather than technical: I assist in interpreting and communicating results, but I am not directly responsible for data management or linking datasets myself.

Q: How familiar are you with RTI/FTI indicators?
A: I am very familiar with them, having worked with these indicators over many years. The important indicators reappear consistently across monitoring reports, which has made this an ongoing learning process.

Q: What challenges have you faced with existing monitoring systems?
A: Monitoring has often been carried out manually in Excel, linking data across multiple sheets. Challenges include the timeliness and reliability of data sources, ensuring comparability between national and international sources (e.g., OECD, EU, Austrian statistics), and meeting policy needs when data are outdated or fragmented. Questions often arise about interpretation: what the data mean, the message they convey, and their policy relevance.

Evaluation of the Dashboard Prototype

Q: Was the installation and setup process understandable when demonstrated?
A: Yes, it was very clear and well explained.

Q: Would you feel confident performing the setup process yourself?
A: With guided instructions or a demo, yes. Without narrative guidance or feedback, it would be difficult. Clear instructions and step-by-step support are necessary.

Q: Were the steps in the configuration assistant logical and understandable?
A: Yes. The process is logical, structured, and can be learned over time.

Q: Could a policymaker without technical knowledge configure the dashboard?
A: Not without guidance. Policymakers under time pressure and without prior dashboard experience would struggle. However, with support and training, users familiar with indicators could learn to use it effectively.

Q: Was the process of uploading and mapping data understandable?
A: Yes, it was very clear and corresponded to a logical workflow.

Q: What was your first impression of the dashboard interface?
A: Dashboards are impressive because they provide immediate visualization and interactivity. Compared to Excel sheets, this dashboard represents a completely different dimension, offering added value for analysis and communication. It is also suitable for presentations.

Q: Was the dashboard visually appealing or overwhelming?
A: It was not overwhelming. On the contrary, it was minimalistic and reduced to the essentials, which makes it understandable and low-threshold.

Q: Was it clear what kind of data the dashboard was showing?
A: Yes, although information on data sources was not always visible in the final visualization. Data provenance is important, so the source of each indicator should be consistently displayed.

Q: Did the grouping of areas, subareas, and indicators make sense?
A: Yes. The grouping follows a logical structure based on data availability. It was also interesting to see that some indicators appeared multiple times, which suggests opportunities for linking or bridging across categories.

Q: How relevant is this type of dashboard for your work?
A: Very relevant. Tools such as the FTI Monitor have already set a precedent, and dashboards are becoming increasingly important in political work. They are more agile and up-to-date than long reports, which few people read. At the same time, there should remain options for exporting results (e.g., PDF or print versions), since data updates may cause results to change over time. A function to save or bookmark searches would also be valuable.

Q: Would this dashboard be helpful for identifying problems or tracking progress?
A: It is particularly useful for tracking progress and understanding developments. For problem identification, however, additional qualitative analysis is required to provide context and explain underlying causes.

Q: Which parts of the dashboard seemed most useful or least useful?
A: The overall overview is the most useful, as it provides a broad picture before focusing on details. Each step in the workflow is essential, so I would not consider any part unnecessary.

Q: Did the use of colors, layout, and labels support understanding?
A: Yes, the color scheme was helpful. The main missing element was clearer indication of data sources within the visualization.

Q: Were there elements that were confusing or difficult to interpret?
A: No. Nothing was confusing; it was simply new and required some learning.

Q: What is one thing you would improve about the dashboard?
A: The most important improvement would be to provide more explanatory support, such as info boxes, tooltips, or digital help. Small demos or showcases would also be very useful, guiding users through the setup or dashboard functions step by step.

Q: Is there anything missing that you would expect?
A: Additional explanatory material and the ability to save or export results would be valuable enhancements.

Summary The participant highlighted the dashboard's added value compared to manual Excel-based monitoring, particularly for its visualization, interactivity, and communication potential. The configuration process was seen as logical, but users without prior dashboard experience would need guidance. Key suggestions for improvement included consistent display of data sources, enhanced explanatory support (tooltips, demos, showcases), and options to export or save results for future reference.

Datasets Used in Demonstration

Table 2 lists the open government datasets used in the demonstration of the RTI Dashboard prototype. All datasets were retrieved from the European data portal (`https://data.europa.eu/`) in August 2025.

Dataset Title	**Description**	**Source / Link**
Enterprises with internet access	Indicators on companies' access to and use of the internet and digital technologies in Austria.	`https://data.europa.eu/data/datasets/ae76e610-e2f6-3c71-814b-56d8e3d9349a?locale=en`
Households with internet access	Data on household internet connectivity in Austria, disaggregated by type of connection and other factors.	`https://data.europa.eu/data/datasets/48dc40c8-da3a-35ad-9b93-0237a1137592?locale=en`
ICT specialists	Indicators on ICT professionals in Austria, including employment and demographic characteristics.	`https://data.europa.eu/data/datasets/0b4dfb5a-8d10-3ec8-9c7a-77f588b5f43c?locale=en`
Household internet use by age and gender	Household internet usage in Austria disaggregated by age groups and gender.	`https://data.europa.eu/data/datasets/dfb30151-297d-3c95-9d6f-5d20e1691b6d?locale=en`

Table 2: Open government datasets used in the dashboard demonstration.

Bibliography

[1] Carli R, Albino V, Dotoli M, Mummolo G, Savino M. A dashboard and decision support tool for the energy governance of smart cities; 2015. p. 23-8.

[2] Chokki AP, Simonofski A, Frénay B, Vanderose B. Engaging Citizens with Open Government Data: The Value of Dashboards Compared to Individual Visualizations [Article]. Digital Government: Research and Practice. 2022;3(3). Cited by: 10; All Open Access, Bronze Open Access. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85146429325&doi=10.1145%2f3558099&partnerID=40&md5=1452367bb8d7afc1bdfac9dec75d9f77.

[3] Ghazinoory S, Farazkish M, Nasri S, and AM. Designing a science, technology, and innovation (STI) evaluation dashboard: a comprehensive and multidimensional approach. Technology Analysis & Strategic Management. 2023;35(8):1005-23. Available from: https://doi.org/10.1080/09537325.2021.1990877.

[4] Matheus R, Janssen M, Maheshwari D. Data science empowering the public: Data-driven dashboards for transparent and accountable decision-making in smart cities [Article]. Government Information Quarterly. 2020;37(3). Cited by: 232; All Open Access, Green Open Access, Hybrid Gold Open Access. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85044786511&doi=10.1016%2fj.giq.2018.01.006&partnerID=40&md5=69ea19c075506610ccfd9e35f11a12f8.

[5] Moura R, Nascimento M, Valença G, Brito K, Fraga G, Peixoto S, et al. Developing a BI Solution for Public Process Monitoring. Conference on Digital Government Research. 2025 05;1.

[6] Musharu T, Marx Gómez J. In: Developing a Digitisation Dashboard for Industry-Level Analysis of the ICT Sector; 2024. p. 75-93.

[7] Piquet B, Cabrera H, Hernández-Calderón JG, Montane-Jimenez L, Soto-Mendoza V. Dashboard design for Key Performance Indicators visualization of STEAM government initiatives: A case study; 2024. p. 1-9.

[8] Vila RA, Estevez E, Fillottrani PR. The design and use of dashboards for driving decision-making in the public sector; 2018. p. 382 – 388. Cited by: 17. Available

from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85051430746&doi=10.1145%2f3209415.3209467&partnerID=40&md5=315fb0a33e8bbd9488a77519975ab4b7.

[9] Zuo C, Ding L, Liu X, Zhang H, Meng L. Map-based dashboard design with open government data for learning and analysis of industrial innovation environment [Article]. International Journal of Cartography. 2023;9(1):97 – 113. Cited by: 4. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85131751859&doi=10.1080%2f23729333.2022.2049106&partnerID=40&md5=5a54a3f9e1a0808e8cf40d410cb8721e.

[10] Ballantyne P, Singleton A. Using composite indicators and city dashboards to promote place-based policy interventions. Cities. 2024;154:105329. Available from: https://www.sciencedirect.com/science/article/pii/S0264275124005432.

[11] Peffers K, Tuunanen T, Rothenberger MA, Chatterjee S. A Design Science Research Methodology for Information Systems Research. Journal of Management Information Systems. 2007;24(3):45-77.

[12] Kitchenham B, Charters S. Guidelines for performing Systematic Literature Reviews in Software Engineering. 2007 01;2.

[13] Runeson P, Höst M, Rainer A, Regnell B. Case Study Research in Software Engineering: Guidelines and Examples. Hoboken, NJ: John Wiley & Sons; 2012.

[14] Open Government Partnership. Open Government Partnership; 2025. Accessed: 2025-04-30. Available from: https://www.opengovpartnership.org/.

[15] Few S. Information Dashboard Design: The Effective Visual Communication of Data. O'Reilly Media, Inc.; 2006.

[16] Yigitbasioglu OM, Velcu O. A review of dashboards in performance management: Implications for design and research. International Journal of Accounting Information Systems. 2012;13(1):41-59. Available from: https://www.sciencedirect.com/science/article/pii/S1467089511000443.

[17] Tufte ER. Visual Display of Quantitative Information. Graphics Press; 2006.

[18] Amer T. Bias Due to Visual Illusion in the Graphical Presentation of Accounting Information. Journal of Information Systems. 2005 03;19:1-18.

[19] Amer T, Ravindran S. The Effect of Visual Illusions on the Graphical Display of Information. Journal of Information Systems. 2010 03;24.

[20] Janes A, Sillitti A, Succi G. Effective dashboard design [Article]. Cutter IT Journal. 2013;26(1):17 – 24. Cited by: 53. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84874583827&partnerID=40&md5=42c535c6fb3a1a684b9dbcec684ac433.

[21] Sarikaya A, Correll M, Bartram L, Tory M, Fisher D. What Do We Talk About When We Talk About Dashboards? IEEE Transactions on Visualization and Computer Graphics. 2019;25(1):682-92.

[22] Bach B, Freeman E, Abdul-Rahman A, Turkay C, Khan S, Fan Y, et al. Dashboard Design Patterns [Article]. IEEE Transactions on Visualization and Computer Graphics. 2023;29(1):342 – 352. Cited by: 70; All Open Access, Green Open Access. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85139512333&doi=10.1109%2fTVCG.2022.3209448&partnerID=40&md5=95c9ca0899c8321fdf4788e89b55db44.

[23] Martins N, Martins S, Brandão D. Design Principles in the Development of Dashboards for Business Management [Book chapter]. Springer Series in Design and Innovation. 2022;16:353 – 365. Cited by: 6. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85130941804&doi=10.1007%2f978-3-030-79879-6_26&partnerID=40&md5=08a12fdfc77a3dc335205411ed714ad3.

[24] Juice Analytics. A Guide to Creating Dashboards People Love to Use: Translating Delicious Data into a Beautiful Design; 2015. Accessed: May 2025. Available from: https://www.juiceanalytics.com.

[25] Smuts M, Scholtz B, Calitz A. Design Guidelines for Business Intelligence Tools for Novice Users. vol. 28-30-September-2015; 2015. Cited by: 3. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84959431827&doi=10.1145%2f2815782.2815788&partnerID=40&md5=f2fc28815d0aff703770f63999be4d67.

[26] Dowding D, Merrill JA. The Development of Heuristics for Evaluation of Dashboard Visualizations. Applied Clinical Informatics. 2018;9(3):511-8.

[27] Zhuang M, Concannon D, Manley E. A Framework for Evaluating Dashboards in Healthcare. IEEE Transactions on Visualization and Computer Graphics. 2022;28(4):1715-31.

[28] Fan M, Wang Y, Xie Y, Li FM, Chen C. Understanding How Older Adults Comprehend COVID-19 Interactive Visualizations via Think-Aloud Protocol. International Journal of Human–Computer Interaction. 2023;39(8):1626-42.

[29] Yi JS, ah Kang Y, Stasko JT, Jacko JA. Toward a Deeper Understanding of the Role of Interaction in Information Visualization. In: IEEE Transactions on Visualization and Computer Graphics. vol. 13; 2007. p. 1224-31.

[30] Setlur V, Correll M, Satyanarayan A, Tory M. Heuristics for Supporting Cooperative Dashboard Design [Article]. IEEE Transactions on Visualization and Computer Graphics. 2024;30(1):370 – 380. Cited by: 9; All Open Access, Green Open Access, Hybrid Gold Open Access. Available from: https://www.scopus.com/inwar

d/record.uri?eid=2-s2.0-85181177748&doi=10.1109%2fTVCG.2023.3327158&partnerID=40&md5=db9e1abcbaa4ffdd249f6e3a131981c7.

[31] Beebe SA, Beebe SJ, Ivy DK. Communication: Principles for a lifetime. Allyn & Bacon Boston, MA; 2010.

[32] Shi Y, Gao T, Jiao X, Cao N. Breaking the fourth wall of data stories through interaction. IEEE Transactions on Visualization and Computer Graphics. 2022;29(1):972-82.

[33] Ruoff M, Gnewuch U, Maedche A, Scheibehenne B. Designing Conversational Dashboards for Effective Use in Crisis Response. Journal of the Association for Information Systems. 2023;24(6):1500-26. Available from: https://aisel.aisnet.org/jais/vol24/iss6/7.

[34] Burton-Jones A, Grange C. From Use to Effective Use: A Representation Theory Perspective. Information Systems Research. 2013 09.

[35] Gupta S, Bostrom RP. Technology-mediated learning: A comprehensive theoretical model. Journal of the Association for Information Systems. 2009;10(9):686-714.

[36] Toreini P, Langner M, Maedche A, Morana S, Vogel T. Designing Attentive Information Dashboards. Journal of the Association for Information Systems. 2021 05;22.

[37] Ma Q, Millet B. Design Guidelines for Immersive Dashboards. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 2021 09;65:1524-8.

[38] Ghazisaeidi M, Safdari R, Torabi M, Mirzaee M, Farzi J, Goodini A. Development of performance dashboards in healthcare sector: Key practical issues [Article]. Acta Informatica Medica. 2015;23(5):317 – 321. Cited by: 75; All Open Access, Green Open Access. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84944877276&doi=10.5455%2faim.2015.23.317-321&partnerID=40&md5=92a3f0c9e7f0a43729869ce20dda2b76.

[39] Seitz V, Harvey C, Ikuma L, Nahmens I. A case study identifying key performance indicators in public sectors. In: Seitz V, Harvey C, Ikuma L, Nahmens I, editors. IIE Annual Conference and Expo. Saint-Antoine Ouest, Montreal, Canada; 2014. p. 371-7.

[40] Lohman C, Fortuin L, Wouters M. Designing a performance measurement system: A case study. European Journal of Operational Research. 2004 July;156(2):267-86.

[41] Sørup CM, Jacobsen P, Forberg JL. Evaluation of emergency department performance—a systematic review on recommended performance and quality-in-care measures. Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine. 2013;21(62).

[42] Rasmussen N, Chen C, Bansal M. Business Dashboards: A Visual Catalog for Design and Deployment. Hoboken, NJ: John Wiley & Sons; 2009.

[43] Nasir AHM, Surin ESM, Ahmad MN. Towards Unified Information Dashboard Design - Common Principles, Practices, and Challenges. Procedia Computer Science. 2024;234:1586-92. Seventh Information Systems International Conference (ISICO 2023). Available from: https://www.sciencedirect.com/science/article/pii/S1877050924005209.

[44] Nasir A, Salwana E, Ahmad M. Integrating Information Governance as the Foundation for Information Dashboard Design Ontology. Journal of Information Technology Education: Innovations in Practice. 2025 01;24:001.

[45] Maheshwari D, Janssen M. Dashboards for supporting organizational development: Principles for the design and development of public sector performance dashboards. vol. 2014-January; 2014. p. 178 – 185. Cited by: 15. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84939142770&doi=10.1145%2f2691195.2691224&partnerID=40&md5=7b4dcf3e5f65fc24e3f184d471e62e19.

[46] Lafortune G, Gonzalez S, Lonti Z. In: Malito DV, Umbach G, Bhuta N, editors. Government at a Glance: A Dashboard Approach to Indicators. Cham: Springer International Publishing; 2018. p. 207-38. Available from: https://doi.org/10.1007/978-3-319-62707-6_9.

[47] R S, K K, L MF. Indicator dashboards in governance of evidence-informed policymaking: Thoughts on rationale and design criteria. Luxembourg (Luxembourg): Joint Research Centre (JRC), European Commission; 2022. KJ-09-22-277-EN-N (online).

[48] Cepero T, Montane L, Maestre G. A framework for designing user-centered data visualizations in smart city technologies. Technological Forecasting and Social Change. 2025 01;210.

[49] Jabareen Y. Building a Conceptual Framework: Philosophy, Definitions, and Procedure. Int J Qual Methods. 2009 12;8.