

Article

From Roadmap to Ecosystem: A Comprehensive Framework for Implementing Business Intelligence in Higher Education Institutions

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Abstract

Higher Education Institutions (HEIs) face increasing pressure to transform fragmented information environments into cohesive, data-driven ecosystems that support strategic and operational decision-making. This study proposes a comprehensive framework for implementing Business Intelligence (BI) in HEIs, evolving from a validated roadmap to an integrated ecosystem perspective. Grounded in the Design Science Research methodology, the work combines a systematic literature review, the design of a flexible BI architecture, and an in-depth case study at the University of Trás-os-Montes and Alto Douro (UTAD). The framework addresses critical factors such as strategic alignment, data governance, and system interoperability, and demonstrates how dashboards and analytics can enhance institutional intelligence and evidence-based management. Results from the UTAD case confirm the framework's capacity to overcome technical and organisational barriers, enabling the transition from isolated systems to intelligent, interconnected data infrastructures. This research contributes to the literature by bridging theoretical guidelines and practical implementation, providing a scalable reference model to guide BI-driven digital transformation in higher education. It also demonstrates the tangible institutional value of integrated BI ecosystems in supporting more informed, timely, and efficient decision-making.

Keywords: Business Intelligence; Higher Education Institutions; data ecosystem; decision support; digital transformation



Academic Editor: Mitsuru Kodama

Received: 1 October 2025

Revised: 30 October 2025

Accepted: 10 November 2025

Published: 18 November 2025

Citation: Sequeira, R.; Reis, A.; Branco, F.; Alves, P. From Roadmap to Ecosystem: A Comprehensive Framework for Implementing Business Intelligence in Higher Education Institutions. *Systems* **2025**, *13*, 1032. <https://doi.org/10.3390/systems13111032>

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1. Introduction

Higher Education Institutions (HEIs) operate in an era of unprecedented complexity, characterised by global competition, accelerated technological change and heightened demands for transparency and accountability. Over the past decade, the exponential growth of heterogeneous data from academic management systems, research repositories, learning platforms and student engagement tools has intensified the need to integrate, curate and analyse timely and reliable information to support strategic alignment and operational efficiency [1–4]. The massification of enrolments, budgetary pressures and evolving expectations from stakeholders further reinforce the imperative for evidence-based decision making as a foundation for institutional performance and sustainable development [1,5,6].

Business Intelligence (BI) has consequently emerged as a central enabler of digital transformation in higher education. By converting raw institutional data into actionable insights, BI supports the formulation of strategic objectives, the monitoring of Key Performance Indicators (KPIs) and the early identification of trends that inform both academic and administrative decisions [2,7–9]. Recent studies show that HEIs that progress towards higher levels of BI maturity achieve measurable improvements in organisational agility, student success, financial sustainability and research productivity, which highlights the strategic importance of advanced analytics across institutional domains [7,10–12]. In parallel, advances in cloud computing, big-data processing, Artificial Intelligence (AI) and interactive visual analytics have shifted BI capabilities beyond descriptive reporting towards predictive and prescriptive decision support, allowing institutions to anticipate scenarios such as enrolment dynamics, financial risk and student retention with greater accuracy [8,11,13,14]. Cloud-based services and enterprise data platforms enable automated Extract Transform Load (ETL) processes, scalable data warehousing and interactive dashboards accessible to diverse stakeholder groups, which strengthens cross-institutional intelligence and collaboration [9,12,15].

Despite these opportunities, many universities continue to face persistent obstacles to BI adoption. Typical barriers include fragmented legacy systems, weak data governance, cultural resistance to change and limited analytical skills among staff [1,5,16]. Achieving interoperability, therefore, requires not only technological integration but also demands shared data definitions, robust privacy safeguards and clear governance responsibilities across units and levels of decision making [4,6,17,18]. Leadership commitment and continuous capacity-building are equally decisive, since fear of increased transparency and insufficient training frequently constrain the effective use of analytics in daily practice [5,16,19].

The academic literature offers important, albeit partial, responses to these challenges. Several contributions propose governance and performance frameworks that enhance data quality, consistency and accountability across institutional contexts [3,7,18,20]. Others examine dashboard design and KPI selection to support strategic, tactical and operational decision making, and explore the integration of BI with predictive modelling and Machine Learning (ML) to improve forecasting accuracy and intervention capacity [9,12,13,21]. Nevertheless, existing approaches often address isolated components, for example, technical architecture, stakeholder engagement or specific analytical techniques, and seldom offer a validated, end-to-end roadmap capable of guiding HEIs across all phases of BI adoption, from strategic planning to operational deployment and continuous improvement [10,15,22].

This article addresses that gap by presenting the corollary of a doctoral research programme that developed, tested and refined a comprehensive framework for BI implementation in HEIs. Grounded in the Design Science Research (DSR) methodology, the work synthesises the outcomes of a Systematic Literature Review (SLR), the design of a scalable BI architecture and an extensive case study at the University of Trás-os-Montes and Alto Douro (UTAD), a Portuguese public HEI. The proposed framework extends a previously validated roadmap into an integrated ecosystem perspective and demonstrates, through empirical validation, how HEIs can overcome technical and organisational barriers to achieve intelligent, interconnected data infrastructures that support timely, informed and effective decision making. The research builds on a sequence of peer-reviewed contributions that progressively developed and validated the BI roadmap, from its initial proposal [23] to sector-specific applications in hospitality and tourism [24] and culminating in the empirical validation and data-engineering architecture for higher education [25–27]. These efforts converge in a comprehensive model capable of guiding BI-driven digital transformation and offering a scalable reference for other HEIs facing similar challenges [28].

The remainder of this article is organised as follows. Section 2 details the materials and methods, describing the DSR process and the multi-phase approach adopted to develop and validate the proposed roadmap. Section 3 presents the main results, highlighting the comprehensive BI framework and its empirical validation through the UTAD case study. Section 4 discusses the implications of these findings for research and practice, identifying opportunities for future investigation and potential extensions of the framework. Finally, Section 5 summarises the principal conclusions and outlines the theoretical and practical contributions of this research to BI in HEIs.

This article represents the final stage of a doctoral research programme that progressively developed and validated the proposed roadmap, culminating in an integrated ecosystem framework for BI adoption in higher education.

2. Materials and Methods

The implementation of a comprehensive BI framework in a HEI requires a research design that ensures scientific rigour while also addressing the organisational and technological complexity typical of academic institutions. To achieve these objectives, this research follows a methodological strategy that combines conceptual development with empirical validation. The approach is anchored in DSR, which enables the creation and iterative refinement of technological artefacts while generating theoretical insights of practical relevance [13,19,23]. DSR supports continuous interaction between theory and empirical evidence, ensuring that the proposed roadmap evolves in line with institutional needs and maturity [28].

The investigation proceeded through three interconnected stages: (i) an SLR to establish the theoretical and empirical foundations of the study; (ii) the design and development of the BI roadmap and technical architecture; and (iii) a case study implementation and validation at the UTAD.

Each stage is described below to ensure transparency and reproducibility, following best practices identified in recent BI research [15–27].

2.1. Systematic Literature Review

The first phase aimed to capture the state of the art in BI adoption within HEIs, focusing on strategic, technological, and organisational factors influencing successful implementation. The literature search and screening followed a structured and replicable process consistent with the principles of the DSR methodology, including database selection, inclusion and exclusion criteria, and double-blind verification of eligible studies [23]. Searches were conducted between 2018 and 2023 across Scopus and Web of Science using combinations of keywords such as BI, higher education, data governance, dashboard, decision support and digital transformation.

The search protocol was iteratively refined through pilot queries to maximise sensitivity and precision. Reference management and screening were supported by double-blind checks of titles, abstracts and full texts. Inclusion criteria retained peer-reviewed articles and conference papers that (i) addressed BI frameworks or systems applied to HEIs; (ii) presented empirical evidence, conceptual models or implementation strategies; and (iii) were published in English between January 2018 and June 2023. Exclusion criteria removed studies lacking methodological detail or purely theoretical discussions. After screening, a final sample of 72 primary studies was selected for detailed analysis [19].

Data extraction covered publication year, research methods, technological platforms and reported outcomes. The analysis revealed recurring Critical Success Factors (CSFs)—including data quality, stakeholder engagement and strategic alignment—as well as common obstacles such as fragmented systems, cultural resistance and insufficient governance

mechanisms [20–22]. Importantly, the review confirmed a significant gap: the absence of a validated, end-to-end roadmap capable of guiding HEIs across all phases of BI adoption, from strategic planning to operational deployment [23,24]. The SLR also highlighted the growing relevance of cloud computing, data-engineering pipelines and real-time analytics for higher education, reinforcing the need for an architecture capable of handling large heterogeneous datasets [29–31].

2.2. Roadmap Design and BI Architecture Development

Building on the SLR findings, the second phase focused on the design of a roadmap that could serve as a sequential and adaptable guide for BI implementation in HEIs. The roadmap integrates strategic, organisational and technological dimensions into six iterative phases: strategic alignment, requirements elicitation, data governance and quality management, architecture design and technology selection, implementation and dashboard development, and evaluation with continuous improvement. Each phase includes defined entry and exit criteria, enabling institutions to adopt the framework according to their own maturity levels [23,25].

To operationalise this roadmap, a technical architecture was developed to ensure interoperability, scalability and compliance with European data-protection requirements. The architecture follows a layered data-engineering model comprising:

- **Data Ingestion Layer:** extraction of structured and semi-structured data from heterogeneous sources (academic management systems, research repositories, financial databases and human resources platforms). Data pipelines were implemented using Azure Synapse Analytics, enabling scheduled and automated ETL processes with built-in error handling and logging for quality assurance [21,23,24,31].
- **Operational Data Store (ODS):** a staging area for cleansing, deduplication and initial transformation of raw data before integration into the Enterprise Data Warehouse (EDW). Automated validation routines ensured referential integrity and metadata consistency [23,25].
- **EDW:** a centralised repository for historical and aggregated data, organised in star-schema models to support multidimensional analysis, Online Analytical Processing (OLAP) and predictive modelling. Partitioning strategies and column-store indexing were applied to optimise query performance and reduce storage costs [23,26,32].
- **Analytics and Visualisation Layer:** interactive dashboards built with Microsoft Power BI, presenting KPIs and trends tailored to strategic, tactical and operational decision levels. Features include drill-down capability, automated alerts and natural-language query functions to support proactive management [23,27].

Security and governance were reinforced through Role-Based Access Control (RBAC), encryption at rest and in transit, and compliance with the General Data Protection Regulation (GDPR), ensuring privacy, reliability and high availability [21,23,24]. By leveraging cloud-based services, the system offers scalability and elasticity to accommodate growth in data volume and complexity, addressing key barriers highlighted in the literature [20–22,29]. The architecture also integrates continuous monitoring components for data lineage and metadata management, enabling real-time detection of anomalies and proactive maintenance [33].

2.3. Case Study Implementation and Validation

The third phase involved the implementation and empirical validation of the proposed roadmap and architecture at UTAD. The university was selected as the pilot site due to its diverse academic portfolio, multi-campus structure and existing challenges in integrating data from multiple operational systems. UTAD serves more than 8000 students and

manages numerous independent information systems, making it an ideal environment to test the scalability of the roadmap.

Implementation began with a comprehensive mapping of institutional data sources and strategic objectives. Semi-structured interviews were conducted with key stakeholders—including members of the rectorate, faculty deans, administrative directors and IT managers—to capture decision-support needs, define relevant KPIs and identify potential barriers. Interview protocols were informed by the CSFs identified in the SLR and included questions on data accessibility, current reporting practices and desired analytical capabilities. Each interview lasted between 45 and 90 min and followed a structured guide organised around three analytical dimensions: organisational, technological, and strategic. This structure ensured consistency across sessions while allowing respondents to elaborate on context-specific challenges and opportunities related to BI adoption. Thematic analysis was inductively applied to identify recurring patterns and stakeholder priorities emerging from the interviews. The interviews were complemented by document analysis of strategic plans, quality assurance reports and existing dashboards [23–27].

Based on these inputs, data pipelines were configured to extract and integrate information from academic, research, and administrative systems into the ODS and EDW, processing millions of historical records that covered multiple academic years and diverse domains such as student enrolment, research projects, and financial transactions [23,25–27]. Azure Synapse Analytics was configured within UTAD’s existing cloud infrastructure, and Power BI dashboards were integrated with institutional authentication and access control policies. Figure 1 summarises the architecture pipeline supporting data ingestion, transformation, and analytics. It contextualises how cloud services and governance mechanisms were integrated so that each component contributes to scalability, interoperability, and data quality assurance. A set of prototype dashboards was developed to support different decision levels:

- Strategic dashboards for the rectorate, focusing on enrolment trends, research productivity, financial performance, and internationalisation indicators.
- Tactical dashboards for faculty and department managers, covering course performance, budget execution, and staff allocation.
- Operational dashboards for administrative staff, providing real-time updates on admissions, room utilisation, and daily financial transactions.

Each dashboard incorporated advanced features such as drill-down functionality, time-series forecasting and automated report generation, enabling decision-makers to monitor key indicators with minimal delay [23,25–27,32]. The validation phase combined expert review sessions with user group testing. Expert reviewers (BI specialists and senior managers) were selected based on experience in data governance and analytics. Validation workshops included six participants per session, using qualitative rubrics and usability metrics to evaluate relevance, clarity, and technical performance.

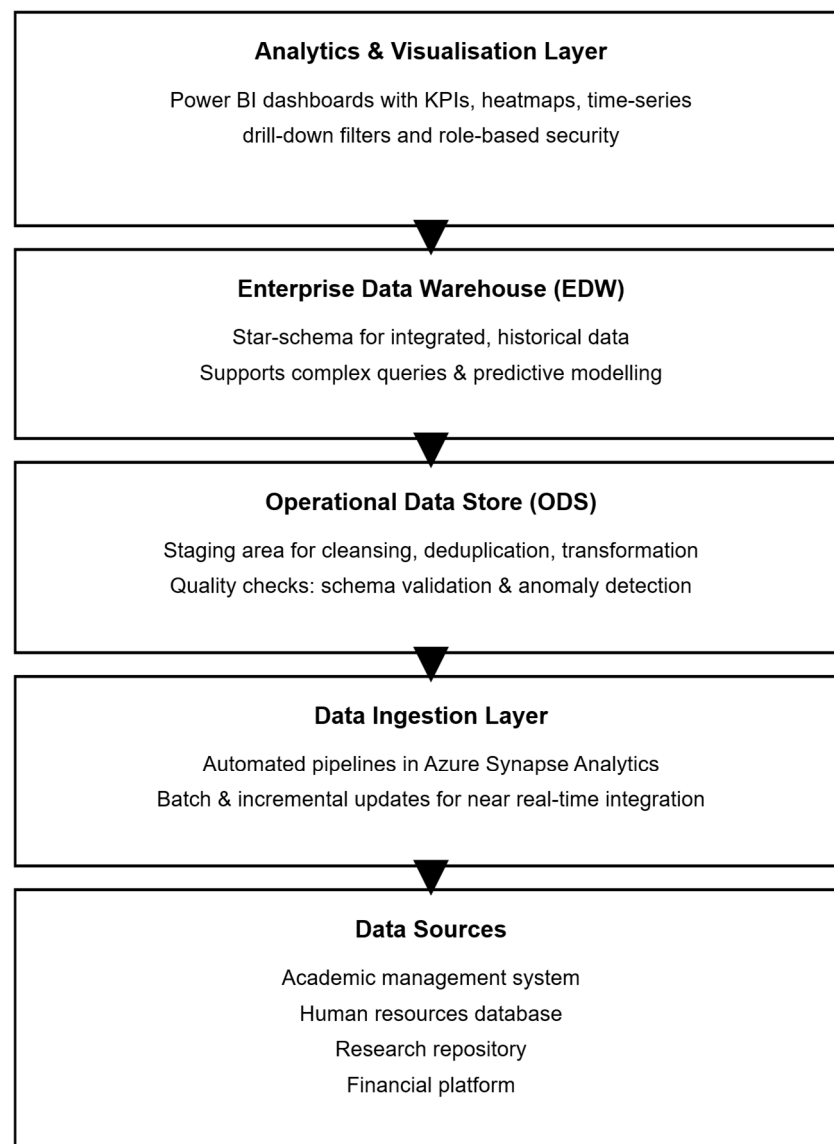


Figure 1. Layered BI architecture implemented at UTAD.

2.4. Validation and Evaluation

Validation followed an iterative process combining expert reviews and user group testing to assess the usability, relevance and technical performance of the roadmap and dashboards. Expert reviews involved BI specialists and senior administrators, who evaluated the conceptual robustness of the roadmap and provided feedback on the architecture's scalability and governance mechanisms [23–27]. User group testing sessions engaged representatives from academic and administrative units in hands-on evaluation of dashboard prototypes.

Feedback was analysed using thematic coding to identify common concerns and opportunities for improvement. Key issues—such as the need for clearer KPI definitions, enhanced drill-down functionality and improved data refresh rates—were addressed in successive design cycles. Quantitative system metrics, including average query response times and dashboard adoption rates, were also monitored to ensure technical performance and user satisfaction [23–27,31]. This iterative refinement ensured that the final roadmap was both theoretically robust and practically viable.

2.5. Data Availability and Ethical Considerations

All data used in this study were drawn from UTAD's internal information systems and processed within the university's secure BI infrastructure. Due to privacy and institutional confidentiality, raw operational data cannot be made publicly available. However, anonymised datasets, dashboard specifications, and process documentation can be provided by the corresponding author upon reasonable request. Because the study focused exclusively on organisational data and voluntary stakeholder feedback, formal ethical approval was not required. Nevertheless, all participants were informed about the research objectives and provided consent for the use of their anonymised responses [23–27].

3. Results

The implementation at UTAD took place between 2021 and 2023 and involved the progressive deployment of the roadmap phases, with iterative feedback loops between academic, administrative, and technical teams. Each phase of the DSR process was aligned with specific institutional objectives, ensuring continuous validation and refinement of the developed artefacts. The results are organised according to the main outputs of each phase, illustrating how the roadmap evolved from conceptual design to operational deployment within the institutional ecosystem. This section presents the consolidated outcomes of the pilot, including the BI architecture, data integration processes, and the dashboards that supported strategic, tactical, and operational decision-making across the university.

3.1. Roadmap for Business Intelligence Implementation

The final roadmap (Figure 2) was conceived as a six-phase, iterative process to guide BI adoption in HEIs. Unlike generic project management plans, the roadmap integrates organisational culture, governance, and technological requirements into a structured sequence of activities [23–27,34]. This figure shows how the six phases interconnect through feedback loops, a central governance layer, and broad stakeholder engagement, reinforcing the transition from a linear implementation model to an evolving BI ecosystem. In addition to the six implementation phases, the figure illustrates the underlying data pipeline (from ingestion to analytics), the central governance layer, and the broad stakeholder engagement that emerged from the UTAD case study. During the UTAD pilot, the roadmap phases were sequentially applied: strategic alignment and KPI mapping (Q1–Q2 2021), data integration and governance setup (Q3–Q4 2021), architecture deployment (2022), and validation with end users (2023). This chronological progression enabled the roadmap to evolve from conceptual design to operational practice, ensuring iterative feedback between institutional strategy, data governance, and technological implementation.

Each phase of the core roadmap is described below.

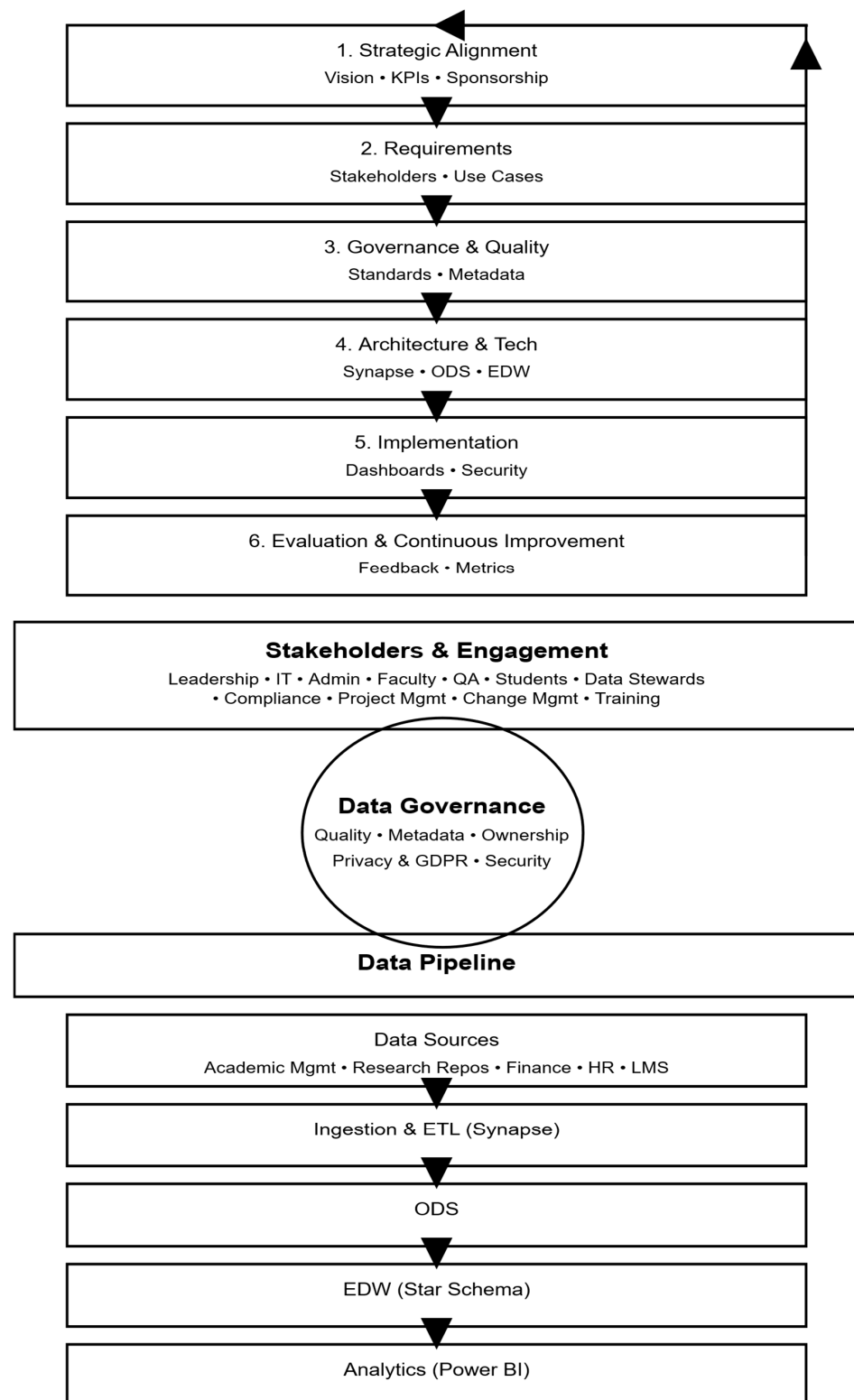


Figure 2. Integrated ecosystem framework for BI implementation in HEIs.

3.1.1. Strategic Alignment

The process begins with the definition of institutional objectives and strategic indicators that BI must support. Interviews and document analyses at UTAD revealed the importance of aligning BI goals with the university's strategic plan and quality assurance framework. KPIs identified at this stage included student enrolment trends, research output, internationalisation ratios, and financial sustainability metrics. Establishing this

alignment ensured that BI implementation would directly contribute to institutional priorities [35,36]. The strategic KPIs defined during this phase are summarised in Table 1, ensuring alignment between BI implementation and institutional priorities across teaching, research, finance, internationalisation, and quality assurance.

Table 1. Strategic KPIs implemented at UTAD, grouped by functional area.

Functional Area	Example KPIs
Teaching & Learning	Student enrolment trends; Graduation rates; Course completion ratios; Dropout rate
Research & Innovation	Number of funded projects; Publications per faculty; Citation impact; External research income
Finance	Budget execution rate; Cost per student; Revenue diversification
Internationalisation	Mobility ratios (incoming/outgoing); International student percentage; Joint programmes
Quality Assurance	Accreditation compliance rate; Student satisfaction index

3.1.2. Requirements Elicitation

This phase focuses on identifying stakeholders, decision levels, and specific information needs. Through 24 semi-structured interviews with UTAD administrators, deans, and IT managers, critical decision-support needs were mapped. Participants emphasised the necessity of integrating academic, research, and financial data to support cross-departmental analyses, highlighting gaps in existing reporting systems [23,24,37].

3.1.3. Data Governance and Quality Management

Data governance emerged as a key enabler of BI success. Policies and procedures were defined to manage metadata, enforce data quality, and ensure compliance with the GDPR. At UTAD, a governance committee was proposed to oversee data standards, resolve data ownership issues, and monitor quality metrics such as data completeness and timeliness [25,26,38].

Previous studies have emphasised the importance of establishing governance models and accountability structures to ensure data quality, consistency, and institutional trust [39,40].

3.1.4. Architecture Design and Technology Selection

Guided by the findings of the SLR, Azure Synapse Analytics was selected as the backbone for data integration and transformation, complemented by Power BI for analytics and visualisation. This choice balanced scalability, cost-efficiency, and compatibility with UTAD's existing Microsoft-based infrastructure. The architecture design also incorporated an ODS and an EDW, ensuring both near real-time and historical analysis capabilities [23,26,31].

3.1.5. Implementation and Dashboard Development

Data pipelines were developed to automate the extraction, transformation, and loading of data from heterogeneous sources. Prototype dashboards were created for three decision levels:

- Strategic dashboards for the rectorate, featuring KPIs on enrolment, graduation rates, research projects, and budget execution.
- Tactical dashboards for faculty and departmental managers, offering visualisations of course performance, staff allocation, and project funding.

- Operational dashboards for administrative staff, providing daily updates on admissions, room usage, and financial transactions.

Each dashboard included drill-down features and custom filters to enable flexible analysis and self-service exploration [23,27,41–43].

3.1.6. Evaluation and Continuous Improvement

The roadmap closes with iterative validation and refinement based on user feedback. Regular review meetings and usability tests ensured that dashboards met stakeholder expectations and that the BI architecture remained adaptable to evolving institutional needs. Key lessons from UTAD included the need for simplified KPI definitions, enhanced user training, and continuous monitoring of data refresh rates. Performance indicators collected during the pilot implementation are reported in Table 2, providing evidence of the architecture’s scalability and reliability, including query response times, data refresh rates, and user satisfaction levels [23,26,42,44].

Table 2. Performance metrics collected during the UTAD pilot implementation.

Metric	Target/Observed Value
Average dashboard query time	<2 s for most dashboards
Data refresh rate—strategic	Every 4 h
Data refresh rate—operational	Every 30 min
Data completeness (ODS checks)	>98%
Anomaly detection accuracy	>95%
User satisfaction (pilot survey)	4.5/5 average rating (administrative staff)

This roadmap differs from prior models by integrating stakeholder engagement throughout all phases and by emphasising governance and continuous improvement, two factors frequently overlooked in earlier BI implementations [23,25,34].

3.2. Business Intelligence Architecture

The second key result was the development of a scalable BI architecture that operationalises the roadmap and ensures robust data engineering and analytics capabilities (Figure 1 illustrates the layered design).

The architecture follows a four-layer structure:

- **Data Ingestion Layer:** Automated pipelines in Azure Synapse Analytics ingest data from UTAD’s academic management system, human resources database, research repository, and financial platform. The pipelines support both batch and incremental updates, allowing near real-time integration of new records [23,26,31].
- **ODS:** Serving as a staging area, the ODS performs data cleansing, deduplication, and transformation. Data quality checks include schema validation and anomaly detection routines to flag inconsistent or missing values [23,25].
- **EDW:** A star-schema EDW stores integrated, historical data for multi-dimensional analysis. The EDW supports complex queries, trend analysis, and integration with advanced analytics tools for predictive modelling [31,34].
- **Analytics and Visualisation Layer:** Power BI dashboards present KPIs through interactive visualisations, including heatmaps, time-series charts, and drill-down filters. Security roles restrict access to sensitive data while enabling broad dissemination of aggregated indicators [27,44].

Performance testing at UTAD demonstrated that the architecture could handle large data volumes with average query response times of less than two seconds for most dashboards. Data refresh rates were set to four hours for strategic dashboards and 30 min for operational dashboards, balancing timeliness with resource efficiency.

3.3. Case Study Validation at UTAD

The third and most critical result was the empirical validation of the roadmap and architecture through a case study at UTAD. Validation followed a mixed-methods approach involving expert reviews, user group testing, and performance metrics.

3.3.1. Stakeholder Feedback

Semi-structured interviews and group sessions provided qualitative evidence of the framework's effectiveness. Participants consistently highlighted the improved accessibility of decision-critical information and the reduction of manual reporting tasks. Faculty managers praised the ability to cross-reference academic performance with financial data, enabling more informed budget allocations and course planning. Several respondents also emphasised the cultural impact of the BI platform, reporting greater trust in data and a shift toward evidence-based discussions during strategic meetings [35,37,38].

3.3.2. Quantitative Performance Indicators

User group testing sessions assessed dashboard usability using a standardised questionnaire covering ease of navigation, visual clarity, and relevance of KPIs. Average satisfaction scores exceeded 4.5 on a 5-point Likert scale. Users valued the drill-down functionality, which allowed them to move from aggregated indicators to detailed departmental or course-level data [37,38].

3.3.3. User Testing and Usability

To evaluate technical performance, metrics such as data latency, query response time, and dashboard availability were monitored over a three-month pilot period. Results showed a 40% reduction in report preparation time compared with previous manual processes. Data accuracy, measured by cross-validation against source systems, exceeded 98%, meeting the predefined quality threshold [23,25,42].

3.4. Critical Success Factors Identified

The validation process confirmed several CSFs for BI adoption in HEIs, which align with the findings of the SLR and provide actionable insights for other institutions [20–23,26]:

- **Leadership Commitment:** Strong support from the rectorate and senior management was essential for overcoming resistance and securing resources.
- **Stakeholder Engagement:** Continuous involvement of academic and administrative staff during requirements gathering and testing improved user acceptance and reduced change-related anxiety.
- **Robust Data Governance:** Clear policies for data ownership, privacy, and quality assurance ensured reliability and compliance with GDPR [25,26].
- **Flexible Technology Stack:** Cloud-based solutions enabled scalability and integration with legacy systems, avoiding costly infrastructure upgrades [41].
- **Iterative Development:** The use of DSR cycles allowed for incremental improvements and quick resolution of issues identified during pilot testing [23,27].

These CSFs provide a transferable set of guidelines for universities aiming to replicate the roadmap in different organisational and cultural settings.

3.5. Visualisation of Results

Figures and tables developed during the case study further illustrate the outputs of the framework:

- Figure 2 presents the extended From Roadmap to Ecosystem framework, combining the validated six-phase roadmap with the underlying data pipeline, governance core, and stakeholder engagement layers [23,34].
- Figure 1 shows the layered BI architecture, detailing data flows from source systems through the ODS and EDW to the Power BI dashboards [31,34].
- Table 1 summarises the strategic KPIs implemented at UTAD, defined during the Strategic Alignment phase and validated with institutional stakeholders to ensure alignment with teaching, research, finance, and internationalisation objectives [35,36].
- Table 2 presents performance metrics collected during the pilot implementation, used to evaluate the scalability and reliability of the BI architecture, focusing on query response times, data refresh rates, data quality, and user satisfaction [38,41,44].

The combination of these artefacts provides both conceptual clarity and practical guidance for HEIs seeking to design institutional BI ecosystems [23,27,34,44]. Building upon these developments, the research produced three principal outcomes: (i) a validated roadmap for the implementation of BI in HEIs, (ii) a scalable BI architecture supporting data engineering, integration, and analytics, and (iii) empirical evidence from the UTAD pilot confirming the feasibility and institutional value of the proposed framework. Together, these outcomes illustrate how HEIs can evolve from fragmented and operationally isolated information systems toward integrated, data-driven ecosystems that support strategic decision-making and organisational learning.

4. Discussion

This discussion interprets the empirical findings in light of the research questions and positions them within the broader literature on BI adoption in higher education. The UTAD case demonstrates that a carefully designed roadmap, combined with a layered architecture and robust data governance, can overcome technological and organisational barriers that have historically hindered BI initiatives in HEIs [23–28,34–44]. The following subsections explore the theoretical and practical contributions of this work, compare the results with international experiences, and highlight the limitations and future research opportunities that emerge from the study.

The framework proved effective due to its iterative alignment between strategic objectives, governance mechanisms, and technological design. The DSR approach facilitated contextual adaptation, enabling the roadmap to evolve according to UTAD's institutional maturity.

4.1. Theoretical Contributions

From a theoretical standpoint, this study advances the understanding of BI adoption in HEIs by combining conceptual and empirical insights within a single validated framework. Previous research has typically examined BI from fragmented perspectives, focusing either on technological solutions [34,35], dashboard development [37,38], or governance models [39,40]. The present work moves beyond these isolated approaches by proposing an integrative roadmap that encompasses strategic, organisational and technological dimensions and validates them through a real-world case study.

The application of DSR adds methodological rigour to the development of the roadmap. DSR's iterative cycles of problem identification, artefact design and empirical evaluation ensure that the framework is both theoretically grounded and tailored to the practical needs of HEIs [37,38]. This approach responds to recent calls for more

design-oriented research in information systems, which emphasise the importance of producing artefacts that are not only theoretically sound but also directly applicable to organisational challenges.

The proposed roadmap also refines existing BI maturity models by illustrating the progression from data silos to integrated ecosystems. Unlike traditional maturity models that merely provide descriptive assessments of BI capabilities, this framework offers prescriptive guidance, detailing the specific steps institutions should follow to achieve higher levels of data integration and analytical sophistication. The UTAD case demonstrates that achieving such maturity requires more than technical upgrades; it demands cultural change, sustained leadership support and continuous user engagement—elements frequently overlooked in earlier frameworks [25,28,31,40].

Moreover, the findings enrich the discourse on digital transformation in higher education. BI is increasingly recognised as a cornerstone of digital transformation strategies, yet empirical studies demonstrating the link between BI implementation and institutional change remain limited [39,40]. The UTAD case provides compelling evidence that BI can act as both a driver and an enabler of digital transformation by fostering data-driven decision making, enhancing transparency and promoting cross-departmental collaboration. The demonstrable improvements in decision-making speed, data accessibility and cross-unit coordination underscore the potential of BI to reshape organisational routines and governance structures.

These findings are consistent with studies highlighting governance and leadership as critical enablers of BI maturity [10,15,18], but extend them by integrating continuous improvement and stakeholder co-design throughout all roadmap phases.

4.2. Practical Implications

The practical implications of this study are equally significant. The roadmap and architecture offer a replicable model for universities seeking to implement BI systems capable of delivering timely, reliable and actionable insights. Several lessons from the UTAD case are particularly relevant for practitioners:

- **Leadership Commitment and Governance:** Strong support from institutional leaders emerged as a decisive factor for success. The involvement of the rectorate and senior management facilitated resource allocation, reduced resistance and signalled the strategic importance of the initiative. The establishment of a dedicated governance committee ensured clear accountability, continuous quality monitoring and compliance with data privacy regulations.
- **Stakeholder Engagement:** Continuous involvement of end-users—from requirements elicitation to dashboard testing—proved essential for ensuring system usability and user acceptance. This participatory approach improved the quality of the dashboards and fostered a culture of trust in data, reducing the perception of BI as a top-down control mechanism and encouraging collaborative problem solving.
- **Technology Selection:** The use of cloud-based platforms (Azure Synapse Analytics and Power BI) enabled scalability and flexibility, allowing UTAD to integrate multiple data sources without costly infrastructure upgrades. Other HEIs can benefit from adopting similar cloud-native solutions to future-proof their BI investments [29,41].
- **Iterative Development:** The adoption of DSR allowed for incremental improvements based on real-time feedback, reducing the risk of large-scale implementation failures. Institutions planning BI projects should consider phased deployments that allow for testing, refinement and gradual expansion.

The UTAD case also demonstrates tangible organisational benefits. Report preparation times were reduced by around 40%, and decision-making processes became faster and

more evidence based. These efficiency gains translate into better resource allocation, improved quality assurance and enhanced responsiveness to external demands such as accreditation agencies and government reporting requirements. The measurable impact on staff workload and on the timeliness of management information shows that BI is not merely a technological upgrade but a catalyst for organisational learning and continuous improvement [42,44].

4.3. Comparison with International Experiences

Comparing the UTAD findings with international experiences further underscores the relevance of the proposed framework. Studies from universities in Europe, North America and Asia report similar challenges in BI adoption, including data fragmentation, lack of governance and resistance to organisational change [34,35,39]. Institutions that successfully overcame these barriers often relied on strong leadership, cross-functional collaboration and iterative development—elements embedded in the present roadmap.

For example, Scandinavian universities highlight the importance of stakeholder participation and transparent communication in fostering a data-driven culture, while North American universities stress the need for flexible architectures capable of integrating learning analytics and predictive modelling tools. The UTAD case aligns with these experiences but adds a distinct contribution by demonstrating how a validated roadmap can systematically guide institutions through each phase of BI adoption, from strategic planning to continuous improvement [42,43].

The European context adds a layer of complexity because of the stringent requirements of the GDPR. The roadmap's explicit inclusion of data governance and privacy compliance provides valuable guidance for institutions operating under similar regulatory frameworks [39,40].

Implementation challenges included initial resistance to organisational change among administrative units and the need for ongoing staff training to strengthen data literacy and ensure sustained BI adoption. These challenges underline the importance of addressing human and cultural factors, a topic discussed further in Section 4.4.

4.4. Limitations and Challenges

Despite its contributions, this study is not without limitations. First, the validation was conducted within a single institution, which may limit the generalisability of the findings. While UTAD shares many characteristics with other medium-sized European universities, differences in governance structures, resource availability and organisational cultures may affect the applicability of the roadmap elsewhere. Future research should therefore replicate the study in diverse institutional contexts to test the framework's adaptability and scalability [42,44].

Second, the evaluation focused primarily on short-term outcomes such as usability, data accuracy and user satisfaction. Longitudinal studies are needed to assess the long-term impact of BI adoption on institutional performance indicators, including student success, research productivity and financial sustainability [34,44].

Third, the technological environment is rapidly evolving. Emerging technologies such as ML, AI and real-time predictive analytics hold the potential to further enhance BI capabilities. Although the proposed architecture was designed to accommodate such innovations, future work should explicitly examine how these technologies can be integrated into the roadmap to support advanced forecasting and decision automation [29,31,41].

Finally, while the roadmap emphasises stakeholder engagement, it does not fully address the training and capacity building required to develop advanced analytical skills among staff. As HEIs increasingly rely on data-driven decision making, investments

in data literacy and professional development will become critical to sustaining BI initiatives [42,44].

Nevertheless, the framework was validated within a single institution, and its generalisation requires further multi-case replication. Future studies should explore cross-institutional benchmarking and long-term impact assessment on performance indicators.

4.5. Future Research Directions

Building on these limitations, several avenues for future research emerge:

- **Multi-Case Studies:** Replicating the roadmap in universities with different governance models, cultural contexts and resource levels would provide deeper insights into its generalisability and the contextual factors influencing BI success.
- **Longitudinal Impact Assessment:** Tracking the long-term effects of BI adoption on key performance indicators could demonstrate the strategic value of BI ecosystems beyond operational efficiencies [34,44].
- **Integration with Emerging Technologies:** Exploring the incorporation of ML, AI and advanced predictive analytics into the existing architecture would enhance forecasting capabilities and decision support [29,31,41].
- **Linkages with Learning Analytics:** Investigating how the roadmap can support the integration of learning analytics with institutional BI could open new possibilities for student success interventions and personalised education.
- **Policy and Governance Studies:** Analysing how regulatory environments, such as GDPR in Europe, influence BI implementation strategies would further enrich the understanding of governance challenges [39,40].

By addressing these areas, future research can refine and extend the proposed framework, ensuring its continued relevance in an evolving technological and regulatory landscape. Such investigations will also provide comparative insights that can guide HEIs in tailoring the roadmap to their specific contexts while benefiting from the core principles validated in this study.

5. Conclusions

This study set out to design, implement, and validate a comprehensive framework for BI adoption in HEIs, culminating in a roadmap that moves beyond isolated decision-support tools to a fully integrated data ecosystem. Grounded in the DSR methodology, the research combined an SLR, the development of a multi-layer BI architecture, and an in-depth case study at the UTAD. The findings demonstrate that a structured, multi-phase approach—encompassing strategic alignment, stakeholder engagement, data governance, technology selection, and continuous evaluation—can effectively guide universities through the complex process of BI implementation and digital transformation.

The validated roadmap presented in this article contributes to both theory and practice in several distinct ways. From a theoretical perspective, it advances current models of BI adoption by integrating organisational, strategic, and technological dimensions into a single, empirically tested framework. Unlike descriptive maturity models, the roadmap provides prescriptive guidance, detailing sequential phases and critical activities necessary to transition from fragmented information systems to cohesive, data-driven ecosystems. The application of DSR reinforces methodological rigour and demonstrates how iterative cycles of design and evaluation can generate artefacts that are scientifically robust and practically relevant. In doing so, this research responds to recent calls for design-oriented studies in information systems and extends the literature on BI maturity by linking conceptual development to operational deployment in the higher education context.

From a practical standpoint, the roadmap and associated BI architecture offer a replicable and adaptable guide for institutional leaders, IT managers, and decision makers who are seeking to introduce advanced analytics into their organisations. The UTAD case showed that the framework can produce tangible benefits, including a 40% reduction in report preparation time, enhanced data accuracy, faster query responses, and improved decision-making agility. The six phases of the roadmap—strategic alignment, requirements elicitation, data governance, architecture design, implementation, and continuous improvement—provide a structured path that other institutions can follow or tailor to their specific contexts. CSFs identified during the validation, such as strong leadership commitment, cross-departmental collaboration, and robust data governance, offer actionable recommendations for institutions embarking on similar BI initiatives and highlight the need to address both technological and cultural dimensions of change.

Beyond operational improvements, the framework supports digital transformation in higher education by fostering a culture of evidence-based management. By democratising access to reliable data through interactive dashboards and self-service analytics, BI enables more transparent and participatory decision-making processes. This cultural shift not only enhances institutional performance but also strengthens accountability to external stakeholders such as accreditation agencies, funding bodies, and government authorities. The UTAD experience illustrates how a carefully governed BI ecosystem can act simultaneously as a driver and an enabler of strategic change, embedding data-driven thinking into daily routines and long-term planning.

The study also provides valuable insights for policymakers and funding agencies. The explicit inclusion of data governance and privacy considerations, particularly compliance with GDPR, offers guidance for institutions operating under strict regulatory environments. By demonstrating how governance mechanisms can be embedded within a BI roadmap, the framework can inform national and regional strategies aimed at promoting data-driven management in higher education systems. Such strategies are increasingly relevant as governments seek to align funding models and quality assurance processes with demonstrable performance indicators.

Despite these contributions, the research acknowledges certain limitations. Validation was conducted within a single Portuguese university, and although UTAD shares characteristics with other medium-sized European institutions, contextual differences in governance structures, resource availability, and organisational cultures may influence the framework's applicability. Moreover, the evaluation focused on short-term outcomes such as usability, data accuracy, and user satisfaction; the long-term impact of BI adoption on institutional performance indicators—such as student retention, research productivity, or financial sustainability—remains to be explored. Rapid technological developments, including ML, AI, and advanced predictive analytics, also present both opportunities and challenges for future BI initiatives. While the proposed architecture was designed to accommodate these innovations, further work is needed to examine how emerging technologies can be integrated to support predictive and prescriptive decision support at scale.

These limitations open several promising avenues for future research. Multi-case studies across diverse institutional contexts would test the generalisability of the roadmap and refine its components based on different governance models and cultural settings. Longitudinal analyses could assess the sustained impact of BI on strategic outcomes, while studies integrating emerging technologies could expand the framework's predictive and prescriptive capabilities. Additional investigation into training strategies and data literacy programmes would help institutions build the human capacity necessary to fully exploit BI systems and maintain a culture of evidence-based management. Comparative

research examining regulatory environments, including GDPR, could further illuminate the relationship between data governance policies and the success of BI initiatives.

Overall, while the roadmap proved highly effective within the UTAD context, its success also depended on contextual factors such as leadership stability, institutional readiness, and prior data governance maturity. Recognising these dependencies is essential for ensuring that future implementations adapt the framework to their own organisational realities.

In conclusion, this research provides a comprehensive, validated framework that bridges the gap between conceptual guidelines and practical implementation of BI in higher education. By combining strategic planning, robust governance, scalable technology, and iterative validation, the proposed roadmap provides a sustainable pathway for BI-driven digital transformation in higher education. The lessons learned from the UTAD case offer actionable insights for universities worldwide, supporting their efforts to become truly data-driven organisations capable of meeting the challenges of an increasingly competitive and information-intensive educational landscape. By embedding governance, culture, and technology within a single, adaptable framework, this study offers both a validated reference model for institutional BI adoption and a conceptual foundation for future innovation in higher education analytics.

Author Contributions: Conceptualization, R.S., A.R., F.B. and P.A.; Methodology, R.S., A.R., F.B. and P.A.; Validation, R.S., A.R., F.B. and P.A.; Formal analysis, R.S., A.R., F.B. and P.A.; Investigation, R.S., A.R., F.B. and P.A.; Resources, R.S., A.R. and F.B.; Data curation, R.S., A.R. and F.B.; Writing — original draft, R.S., A.R. and F.B.; Writing — review & editing, R.S., A.R., F.B. and P.A.; Visualization, R.S., A.R., F.B. and P.A.; Supervision, A.R.; Project administration, A.R., F.B. and P.A.; Funding acquisition, F.B. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the project “UTAD+SUCESO”, operation 06/C06-i07/2024.P8861, approved under the terms of the call RE-06/C06-i07/2024—Impulso Mais Digital—Sub-measure Innovation and Pedagogical Modernization in Higher Education—Programme for Promoting Success and Reducing Dropout Rates in Higher Education, financed by European funds provided to Portugal by the Recovery and Resilience Plan (RRP), in the scope of the European Recovery and Resilience Facility (RRF), framed in the Next Generation UE, for the period from 2021–2026.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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