Engineering a Secure and Traceable System for Diploma Issuance in a Brazilian Federal Institution

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Abstract. *The issuance of academic diplomas in Brazilian federal institutions remains a significant administrative challenge, affected by manual workflows, lack of standardization, and limited security mechanisms. These weaknesses result in slow processing, rework, and exposure to fraud, reflecting broader barriers in the digital transformation of the public sector. In response to these issues, the Ministry of Education mandated the nationwide adoption of secure and standardized digital diploma systems. However, implementation has been hindered by institutional heterogeneity and a lack of integrated tools. This work presents the design and implementation of a secure, auditable, and regulation-compliant system for diploma issuance, developed under the XP1 agile methodology. The system automates both physical and digital diploma generation, integrates with academic platforms, enforces role-based access control, and maintains detailed audit logs to support accountability. The project was conducted over 24 weeks in a real institutional context, with iterative deliveries and active collaboration with administrative staff. Validation involved empirical trials and structured feedback from diploma officers. Results demonstrated a 78.7% reduction in issuance time, fewer operational errors, and high user acceptance.*

1. Introduction

The issuance of academic diplomas in Brazilian higher education institutions remains a critical administrative challenge, often hindered by slow processing, rework, manual procedures, and inconsistent practices across units [Weber et al. 2018]. Legacy systems, disconnected from academic platforms and lacking proper security controls, exacerbate data vulnerability and operational inefficiencies [Gomes et al. 2018]. In some cases, diploma issuance processes remain susceptible to fraud and manipulation, further raising concerns over trust and authenticity [Campelli et al. 2021].

These operational issues reflect broader limitations in the digital transformation of the public sector, where initiatives are frequently constrained by superficial automation, institutional resistance, and limited technical capacity [Albuquerque and Costa 2025, Pavlova et al. 2020, Nascimento et al. 2024]. Simultaneously, increasing student mobility and an estimated global diploma fraud market of over USD 2 billion [Castro and Au-Yong-Oliveira 2021] reinforce the need for secure, standardized, and auditable digital systems.

In response to these challenges, the Brazilian Ministry of Education (MEC) mandated a nationwide implementation of digital diplomas through a series of ordinances [Ministério da Educação (Brasil) 2018, Ministério da Educação (Brasil) 2019,

Ministério da Educação (Brasil) 2021, Conselho Nacional de Educação (CNE) 2018]. These regulations require public institutions to adopt certified digital systems that comply with strict legal, technical, and informational standards. However, the heterogeneity of institutional practices and the lack of integrated solutions continue to hinder effective implementation [Albuquerque and Costa 2025].

This paper presents a technical solution to this problem: the design and implementation of a secure, auditable, and standards-compliant digital diploma issuance system for federal institutions. Developed using the XP1 agile methodology, the system enables both automated and manual issuance of physical and digital diplomas, offering centralized control, role-based access management, and detailed audit trails.

The main contributions of this work include the design of an integrated system that enforces regulatory compliance and enhances traceability; the application of the XP1 agile methodology within a regulation-bound institutional environment; and the implementation of audit and governance features such as exportable reports, access control, and interoperability with national academic platforms.

2. Related Work

Digitalization contributes to process standardization and automation, enhancing transparency and control over public resources [Volodina and Grossi 2024, Antipova 2024]. In academic settings, digital diploma issuance combined with auditing mechanisms improves traceability, authenticity, and secure institutional data access [Tavares et al. 2024].

Several frameworks influenced the proposed system design. The automated reasoning approach in [Zhao et al. 2021] guided the implementation of logs and monitoring features for secure workflows. The modular architecture of *FenixEdu* [Branco 2018] inspired the decoupled design enabling integration with SIGAA, SEI, and SINGU. Administrative workflow formalization concepts from [Martins and Duarte 2014] were applied through structured schemas, validation rules, and audit logs.

National initiatives [Campelli et al. 2021, Weber et al. 2018] focus on compliance but present limited integration and auditability. The proposed system addresses these gaps by unifying authentication, validation, and reporting into a single platform, presenting a replicable model for digital transformation in public education.

Few works offer integrated and regulation-compliant solutions for diploma issuance. This system addresses that gap by aligning architecture, legislation, and audit requirements, presenting a replicable model for digital transformation in public education.

3. Methodology

This section describes the methodological approach adopted to guide system development over a six-month academic period using agile methods adapted to institutional constraints. The development occurred at a Brazilian federal university, with primary stakeholders being public servants involved in diploma issuance, whose feedback shaped system requirements throughout the cycle. The project adopted XP1 [Sauvé et al. 2007], a streamlined Extreme Programming version suited to academic contexts, integrating with existing platforms including

SIGAA [Universidade Federal do Rio Grande do Norte 2006] for academic management and SEI [Ministério da Gestão e da Inovação em Serviços Públicos 2015] for document handling. Figure 1 presents the overall methodology, with iteration details in Figure 2.

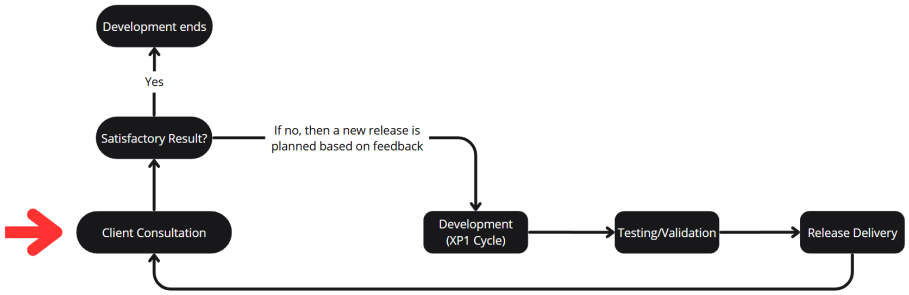

Figure 1. Overall methodological workflow adopted in the project. The XP1 development cycle, highlighted in the figure, is detailed separately in Figure 2.

3.1. Development Methodology

User stories were defined collaboratively with institutional staff, prioritizing functionalities with immediate impact, such as diploma issuance, logging, and SIGAA integration. XP1 was applied through weekly iterations with incremental deliveries and regular client feedback. Figure 2 illustrates the cycle adopted. The process began with requirement gathering and backlog definition, followed by user story creation, task breakdown, and estimation. Acceptance tests were defined early and validated in collaboration with stakeholders. Each iteration concluded with delivery, backlog adjustment, and risk reassessment.

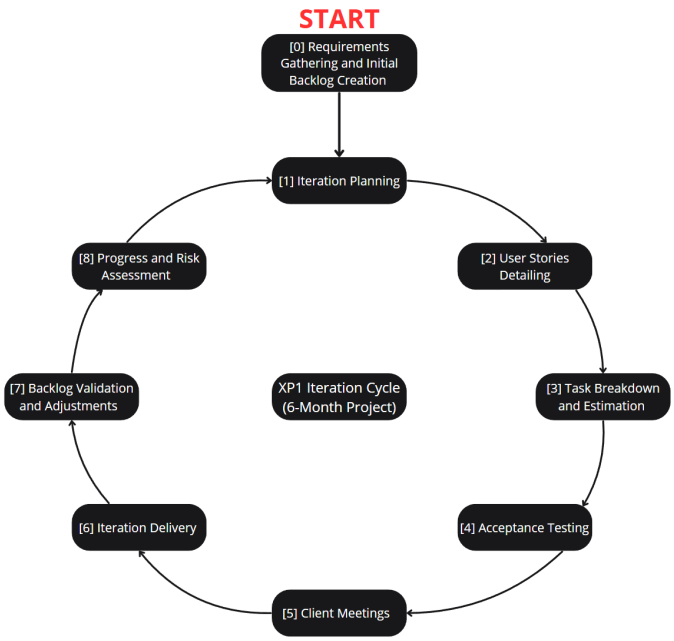

Figure 2. XP1 Iteration Cycle Applied to a 6-Month Institutional Software Project

XP1 was adapted to institutional constraints by reducing overhead and enabling asynchronous collaboration. Iterations were scheduled around staff availability, and feed-

back was collected via shared documents and email. This ensured early integration of compliance requirements without delaying functional progress.

3.1.1. Implementation Phases

The 24-week implementation was structured into four main iterations. Each addressed specific features, with complexity defined by task volume, business logic, external dependencies, and rework potential (see Table 1).

Table 1. Summary of features per development iteration (Iter. = Iteration, Diff. = Difficulty). Difficulty levels were estimated by the developers based on implementation complexity, integration effort, and likelihood of rework.

Iter.	Features	Weeks	Diff.
1	Auth system, user roles, and manual diploma entry with validations.	1–6	Mod.
2	Automatic PDF generation and issuance logging.	7–12	High
3	Reports in PDF/Excel with date filtering.	13–18	Mod.
4	Audit logs with filterable query interface.	19–24	High

3.2. Validation Strategy

The system was validated following XP1 principles of continuous, user-centered feedback [Sauvé et al. 2007]. A triangulated strategy ensured methodological rigor through empirical trials, staff feedback, and technical verification.

Quantitative validation involved controlled issuance attempts before and after implementation, revealing substantial time and error reduction (see Section 4.1). Qualitative validation included feedback from all five diploma staff, confirming usability and workflow improvements (see Section 4.3). Technical validation focused on compliance through audit logs, access control, and data integrity checks (see Section 4.4).

3.3. Technological Stack and Rationale

The system was implemented with tools selected for their modularity, performance, and the development team's prior experience. SvelteKit was preferred over React and Angular due to its compiler-based architecture, which improves load times and supports modular testing [Novac et al. 2024]. Go was chosen for the backend for its simplicity, native concurrency, and efficient resource usage, outperforming traditional frameworks in batch operations [Togashi and Klyuev 2014].

Python was used for diploma rendering due to its flexible libraries for HTML-to-PDF generation [Tournade 2020]. PostgreSQL offered strong transactional guarantees and better performance under concurrent access than MySQL or SQLite [Zapata 2024]. Redis supported caching and rate-limiting with richer data structures and persistence, making it more suitable than Memcached for audit and security needs [Kanthed 2023].

3.4. Architecture and Implementation

The system was designed to ensure compliance, traceability, and secure diploma issuance through a modular, role-based structure. Users select preconfigured MEC portaria profiles, which auto-fill mandatory fields such as course data, director names, and identifiers,

minimizing manual input and standardizing records. Compliance is ensured via schema validation and cryptographic hashes embedded in both the diploma and audit logs, enabling authenticity checks through a public endpoint. A simplified overview of the communication between the front-end and back-end of the system is illustrated in Figure 3.

To ensure auditability, every state-altering operation is recorded with timestamps, user identifiers, and snapshots of data before and after modification. These logs support both institutional governance and legal traceability. Academic data can be fetched automatically to populate diploma fields, while rendered documents are exported in compliant formats (PDF and JPEG). Scalability and fault tolerance are supported through isolated environments, Redis-based caching, and periodic PostgreSQL backups, while a dynamic configuration schema allows for fast adaptation to changing institutional requirements, ensuring long-term maintainability and compliance.

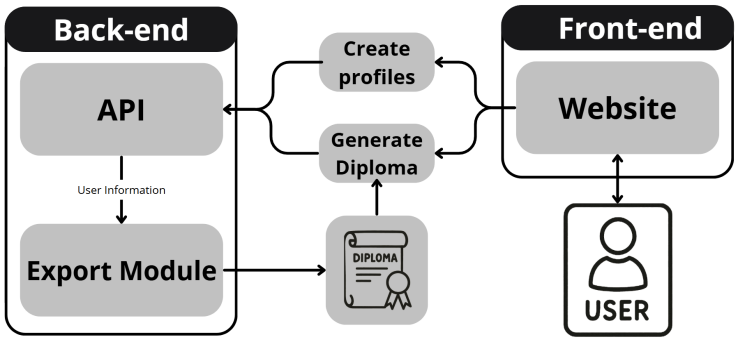

Figure 3. Overview of the system architecture, highlighting the interaction between the user, the web interface, the API, and the modules responsible for diploma generation and export.

3.4.1. Integration with SIGAA and SEI

The system supports both manual data entry and automated integration via a modular API layer. A basic API skeleton was developed to fetch academic data from SIGAA and export diplomas to SEI in compliant formats (PDF and JPEG). As institutions maintain different database schemas, data structures, and naming conventions for student records and course catalogs, the API serves as a customizable template requiring local adaptation. The current implementation performs only read operations using filtered queries, ensuring safe deployment.

4. Results

The results reflect the system's effectiveness evaluation in a real institutional context through controlled task execution, structured staff feedback, and technical component inspection. Although limited to a single university, all relevant stakeholders participated, enabling comprehensive internal assessment.

4.1. Time Reduction and Workflow Optimization

To evaluate the system's impact, five controlled diploma issuance attempts were conducted by the same experienced staff member, comparing the traditional manual method

with the new automated workflow. Each attempt involved the complete process—from data entry to final PDF generation—and was timed precisely.

As shown in Table 2, the average issuance time dropped from 15 minutes and 9 seconds to just over 3 minutes, representing a 78.7% reduction. This improvement is not solely due to automation. Key structural changes also played a role: the system introduces official *portaria* profiles that auto-fill required fields, reducing manual entry and the likelihood of errors.

In the manual process, a single mistake could invalidate the entire document, often forcing users to restart from scratch. This led to a high variability in completion times (±8:11). The new system enables real-time validation and localized corrections, lowering this variability to just ±0:31 and greatly enhancing process consistency.

Table 2. Average diploma issuance time with and without the software, based on five controlled attempts.

Condition	Avg. Time (min:s)	Improvement
Without software	15:09 ± 8:11	—
With software	03:11 ± 0:31	78.7%

4.2. Reduced Errors

To support compliance and reliability, the system was designed to minimize operational errors common in the previous manual process. By automating data entry, enforcing validations, and enabling targeted corrections, it improved standardization, traceability, and auditability. Table 3 presents key errors and their mitigations.

Table 3. Key errors in the previous process and solutions in the new system.

Previous Error	New System Solution
Manual data entry overload	Auto-fill for most fields
Rework after input mistakes	Edit fields without restarting
Crashes and file loss	Stable, tested web platform
Hard to detect inconsistencies	Automated logs and tracking
Unstandardized entries	Templates with validation rules

4.3. User Feedback (Qualitative Assessment)

Qualitative feedback was collected from all five staff members (n=5) through structured interviews conducted individually over a two-week period. Response rate was 100%, with participants having 2-8 years of experience in diploma issuance. These users participated directly in testing and early adoption, providing insights grounded in daily workflows. Overall, the feedback was positive. Users frequently mentioned faster processing, reduced rework, and ease of use after initial adaptation. Figure 4 summarizes the most cited positive aspects and improvement suggestions.

4.4. Audit and Compliance Traceability

The system's audit log, already in production use, ensures traceability by recording all key actions with user ID, timestamps, and data snapshots. This addresses previous gaps in edit tracking and supports institutional compliance. Table 4 outlines the main events logged and their audit relevance.

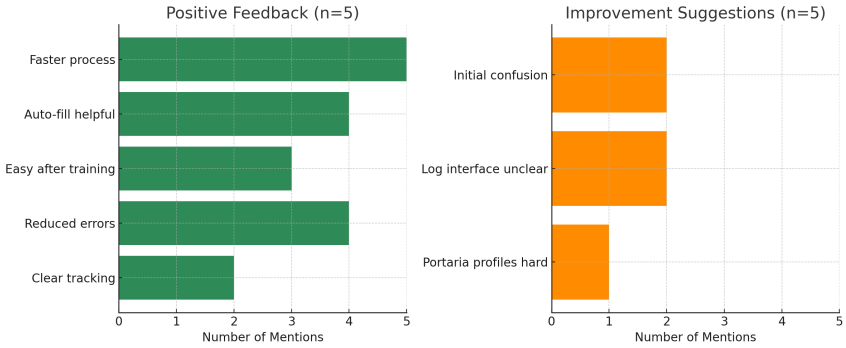

Figure 4. Frequency of recurring feedback themes from diploma issuance staff (n=5)

Table 4. Audit log events, recorded data, and institutional purpose

Event	Recorded Data	Purpose
Diploma creation	User, timestamp, data (before/after), ID	Validate issuance and origin
Field update	Changed fields, old/new values, user	Ensure traceable corrections
Profile selection	Portaria ID, filled data, timestamp	Enforce standard format
File export	User, timestamp, file type, ID	Register output generation
Log access	User, filters, timestamp	Track audit queries

4.5. Discussion

4.5.1. Potential for Broader Adoption

The system proved effective in the integrated IES context, demonstrating that its modular, open-source architecture and secure design can serve as a replicable model for other institutions. For adaptation to other institutions, organizations would need to identify the specific information requirements for their diploma formats and configure the API template to provide these data fields to the proposed system. With such minimal adjustments, similar organizations can benefit from its automation, traceability, and compliance features. As a future goal, the project aims to expand adoption to other public institutions nationwide, reinforcing its scalability and relevance beyond the initial deployment.

4.5.2. Comparison with Related Work

Compared to existing approaches, the proposed system distinguishes itself through its practical alignment with Brazilian regulations and institutional workflows. While [Zhao et al. 2021] and [Branco 2018] offer valuable frameworks for governance and academic management, they lack direct applicability to diploma issuance under MEC mandates. Similarly, [Martins and Duarte 2014] and [Campelli et al. 2021] address relevant aspects of institutional processes and interoperability, but operate at a more abstract level.

The most comparable initiative, [Weber et al. 2018], aligns with regulatory objectives but does not incorporate features such as automation, error correction, or integrated auditing. In contrast, the proposed system delivers a fully operational, traceable, and adaptable platform that meets the specific needs of Brazilian public institutions, effectively bridging the gap between compliance frameworks and real-world implementation.

Table 5. Comparison of related works and the proposed system

System/Study	MEC Compliance	Auditability	Diploma Automation	Brazilian IES Fit
[Zhao et al. 2021]	–	✓	–	–
[Branco 2018]	–	–	–	∼
[Martins and Duarte 2014]	∼	✓	–	∼
[Campelli et al. 2021]	∼	∼	–	✓
[Weber et al. 2018]	✓	–	∼	✓
Proposed System	✓	✓	✓	✓

4.5.3. Limitations

While the system demonstrated promising results in terms of efficiency, compliance, and traceability, its current evaluation is restricted to a single institutional deployment. Broader adoption across diverse public institutions may present challenges related to infrastructural heterogeneity, integration with legacy systems, and differences in administrative workflows. Moreover, the assessment was based on internal testing and qualitative feedback from a limited group of five staff members, which constrains the generalizability of the results. For future work, the system should be deployed in additional institutions to validate its adaptability across varied environments.

5. Conclusion and Future Work

This work presented the development and implementation of a digital diploma issuance system, focused on regulatory compliance, traceability, and operational efficiency within institutional contexts. The main objective was to reduce issuance time, minimize human errors, and provide a technically viable alternative to manual processes in Brazilian public higher education institutions. These goals were achieved, with a 78.7% reduction in issuance time and significant improvements in workflow reliability and standardization.

The system offers a modular, auditable, and adaptable solution that can be replicated by other institutions facing similar challenges. Its secure architecture, coupled with automation mechanisms and integration with academic records, contributes to improving the quality and accountability of diploma issuance. Feedback from stakeholders further confirmed user acceptance, reinforcing the solution's viability in rigid organizational environments..

Despite these advances, the evaluation was limited to a single institution, with feedback obtained from only five administrative staff members. This restricts the generalizability of the results. Moreover, partial integration with legacy systems and the absence of external audits or long-term measurements represent clear limitations. Challenges related to infrastructural heterogeneity, system interoperability, and diversity in institutional workflows are expected in broader deployments.

Future work should prioritize expanding the system to other public institutions, increasing the number of users involved in validation to enable broader feedback and longitudinal analysis. Additional features may include support for other academic certificates, integration with national education databases, a public diploma verification interface, and accessibility and multilingual capabilities to reach a more diverse user base.

Although the system was not originally developed under the Open Institutional Platforms (PIA) initiative of the Brazilian federal government, future iterations should

consider adopting its principles of interoperability, reusability, and scalability.

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