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Implementation of web accessibility in accordance with WCAG 2.1: perceptibility

Implementación de accesibilidad web según WCAG 2.1: perceptibilidad

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Abstract

The university web platform intended for individuals with visual impairments had significant accessibility limitations that restricted independent use. This Integrative Project aimed to implement the perceivability principle of the WCAG 2.1 standard, at conformance level AA, using the agile Rapid Application Development (RAD) methodology, which enabled rapid iterations of design, development, evaluation, and improvement. The main deficiencies identified included the absence of text alternatives, insufficient color contrast, poorly descriptive labels, and inadequate semantic structure. These issues were addressed by incorporating descriptive alt attributes, aria-label attributes, a hierarchical HTML5 structure, and CSS enhancements to improve visibility, focus indication, and keyboard navigation. The evaluation combined automated assessment using TAW, manual testing with the NVDA screen reader, and direct validation with users with visual impairments through Likert-type surveys. Quantitative results showed improvements of more than 2 points across all indicators, reaching scores above 4.4 out of 5, compared with the initial version, which did not exceed 2.5. Qualitative findings revealed a clearer, more structured, and more accessible user experience, with greater ease in identifying interface elements, navigating the platform, and using assistive technologies. These findings demonstrate that applying the perceivability principle not only fulfills the technical requirements of WCAG 2.1 but also has a tangible positive impact on digital inclusion and on the user experience of individuals with visual impairments.

Keywords: web accessibility, WCAG 2.1, perceptibility, visual impairment, accessibility assessment, RAD methodology

Resumen

La plataforma web universitaria para personas con discapacidad visual presentaba limitaciones significativas en accesibilidad, dificultando su uso autónomo. Este proyecto integrador tuvo como objetivo implementar el principio de perceptibilidad del estándar WCAG 2.1, nivel AA, utilizando la metodología ágil Rapid Application Development (RAD), que facilitó iteraciones rápidas de diseño, construcción, evaluación y mejora. Se identificaron deficiencias como la falta de alternativas textuales, bajo contraste de color, etiquetas poco descriptivas y una estructura semántica inadecuada. Estas se corrigieron mediante la incorporación de etiquetas alt, atributos aria-label, una jerarquía estructural en HTML5 y mejoras en CSS para optimizar la visibilidad, el foco y la navegación por teclado. La evaluación combinó herramientas automáticas (TAW), pruebas manuales con el lector NVDA y validación directa con usuarios con discapacidad visual a través de encuestas tipo Likert. Los resultados cuantitativos mostraron incrementos superiores a 2 puntos en todos los indicadores, alcanzando valores superiores a 4.4 sobre 5, en comparación con la versión inicial, que no superaba 2.5. Los resultados cualitativos reflejaron una experiencia más clara, estructurada y accesible, con mayor facilidad para identificar elementos, navegar y usar tecnologías asistivas. Estos hallazgos evidencian que la aplicación del principio de perceptibilidad no solo cumple con los requisitos técnicos del estándar WCAG 2.1, sino que también genera un impacto positivo real en la inclusión digital y en la experiencia de personas con discapacidad visual.

Palabras clave: accesibilidad web, WCAG 2.1, perceptibilidad, discapacidad visual, evaluación de accesibilidad, metodología RAD

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1. Introduction

Web accessibility constitutes a fundamental component of digital inclusion, particularly for individuals with visual impairments, who continue to face persistent barriers when using websites and online platforms. Despite the regulatory and technical efforts promoted by international organizations such as the W3C, numerous studies indicate that most digital environments still pose challenges related to navigation, visual interpretation, and access to information [1].

The Web Content Accessibility Guidelines (WCAG) 2.1, published by the World Wide Web Consortium (W3C), establish a set of guidelines organized around four fundamental principles: perceivable, operable, understandable, and robust. Among these, perceivability is particularly relevant for individuals with visual impairments, as it requires interface components and content to be presented in ways that users can perceive through different sensory channels [1]. This includes requirements such as appropriate alternative text, sufficient visual contrast, hierarchical headings, and compatibility with assistive technologies, including screen readers.

Recent studies have revealed significant gaps between the theoretical framework of the standard and its practical implementation. A systematic review published in Discover Computing showed that many digital platforms do not adequately meet the minimum accessibility criteria for individuals with low vision or blindness, particularly on mobile devices, where perceptual issues are more pronounced [2]. Similarly, an empirical evaluation of major e-commerce websites found that more than 60% of users with visual impairments reported frustration due to the absence of labels, coherent semantic structures, and accessible navigation [3].

In academic settings, studies such as the analysis of higher education institution websites in Finland have shown that compliance with the principle of perceivability varies considerably, even in contexts where digital accessibility is legally required [4]. Qualitative approaches based on the direct experiences of blind users have also highlighted that the limited participation of individuals with visual impairments in platform design and evaluation restricts the actual scope of accessibility [5].

In Ecuador, digital accessibility has increasingly gained recognition as a key component of social and technological inclusion. Regulatory frameworks, such as the Technical Standard on Disabilities, have established guidelines to ensure equitable access to digital platforms for individuals with disabilities, including those with visual impairments [6]. However, the effective implementation of these regulations remains limited. Despite institutional efforts, several studies indicate that many public and educational platforms in the country still present significant barriers for users with visual impairments, particularly in relation to the accessibility principles established by the WCAG [7].

In this context, this study focuses on analyzing the application of the perceivability principle of the WCAG 2.1 standard in a university web platform designed to facilitate access to digital content for individuals with visual impairments. One relevant example is the use of tools that convert text documents into audio, such as those employed in academic settings for assisted reading, which have proven to be key inclusion strategies when incorporated into accessible platforms from the design stage [8]. However, various studies indicate that many of these systems do not meet the minimum accessibility criteria established by the WCAG, which hinders both content perception and interaction through assistive technologies.

In response to this problem, the study addresses the following research question: To what extent does the application of the perceivability principle of the WCAG 2.1 standard in university web platforms improve accessibility for individuals with visual impairments? To this end, an agile Rapid Application Development (RAD) methodology was adopted, as this approach is widely used in the development of accessible solutions [9]. The process included an initial evaluation using the TAW Web Accessibility Test tool [10], the definition of technical requirements, the redesign of accessible interfaces through Figma prototypes, the progressive implementation of improvements, automated validation, manual testing, and final evaluation with real users. This approach seeks to demonstrate the impact of systematically integrating accessibility guidelines into the design and development of inclusive digital platforms in educational contexts [11].

2. Materials and Methods

2.1. Development Methodology

The implementation of accessibility improvements was carried out using the RAD approach. This methodology was selected because it enables short cycles of development, review, and continuous improvement, which is appropriate for an iterative process aimed at correcting accessibility barriers [12].

The RAD model enabled the work to be structured into four phases: requirements analysis, analysis and design, construction, and evaluation.

2.2. Tools and Materials

For the development and evaluation of the project, the following resources were used:

- **Automatic evaluation tool:** TAW (Web Accessibility Test), used for the initial and final analysis of compliance with the WCAG 2.1 guidelines.

- **Assistive technology:** the NVDA screen reader, employed in manual evaluations of navigation and web content reading.
- **Reference standard:** the guidelines associated with the perceivability principle of the WCAG 2.1 standard, level AA.
- **Data collection instruments:** satisfaction questionnaires and semi-structured interviews to obtain qualitative feedback from end users.

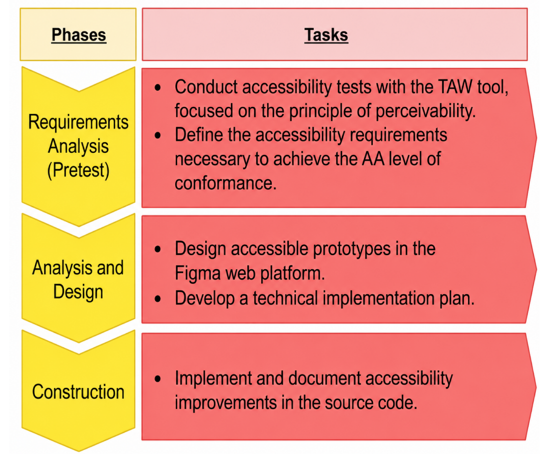

Figure 1. Procedure for implementing accessibility improvements.

Although TAW enabled initial and final automated evaluations of compliance with the criteria associated with the perceivability principle, its use involves methodological limitations that must be considered. In particular, automated tools cannot comprehensively assess aspects related to the quality of the user experience, the contextual interpretation of content, the clarity of instructions, the appropriateness of alternative texts, or actual interaction with assistive technologies. Likewise, elements classified as warnings or non-verifiable require manual review to determine whether they constitute real accessibility barriers. For this reason, the results obtained with TAW were complemented by manual testing with the NVDA screen reader and direct validation with users. Additionally, other evaluation tools, such as Axe and WAVE, may provide complementary assessments by detecting issues that a single automated platform may not identify in the same way.

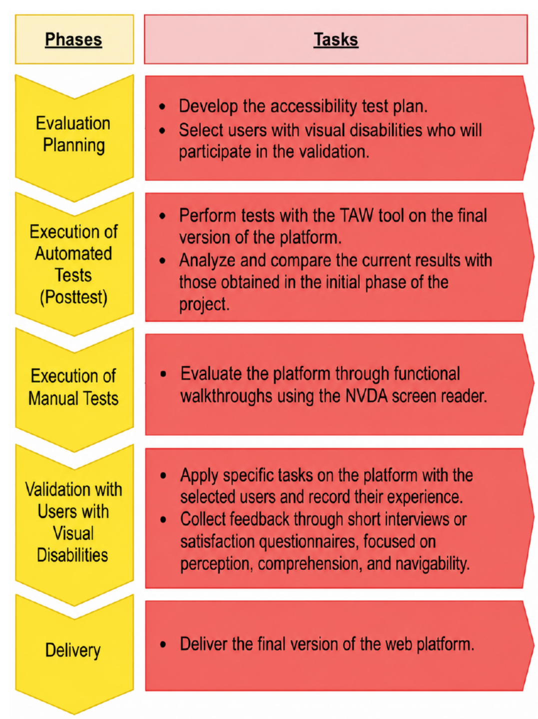

Figure 2. Procedure for the evaluation of the impact of the improvements.

2.3. Training Methods

The study consisted of two main stages: the implementation of accessibility improvements in accordance with the perceivability principle of WCAG 2.1 and the evaluation of their impact on the accessibility of the web platform.

Figure 1 shows the workflow followed during the implementation of the technical improvements.

The impact of the implemented improvements was then evaluated through five phases: planning, execution of automated tests, manual testing, validation, and delivery. This process enabled validation of the final version of the web platform. The tasks corresponding to each phase are detailed in Figure 2.

2.4. Initial Evaluation (Pretest)

To conduct the initial accessibility evaluation based on the perceivability principle of WCAG 2.1, at conformance level AA, a specific development branch named "test" was created within the original web project. This version was adapted for automated evaluation by removing security layers, such as token-based authentication and performing a user data dump. This allowed the analysis tool to access each key section of the platform directly.

Subsequently, this version of the system was deployed on a virtual machine through the Azure portal, providing an internet-accessible testing environment. The URLs of the ten main pages of the web platform were then identified and collected, including the login, user registration, dashboard, global settings, content extractor, player, institutional information, user profile, password recovery, and new password request interfaces, as shown in Figure 3.

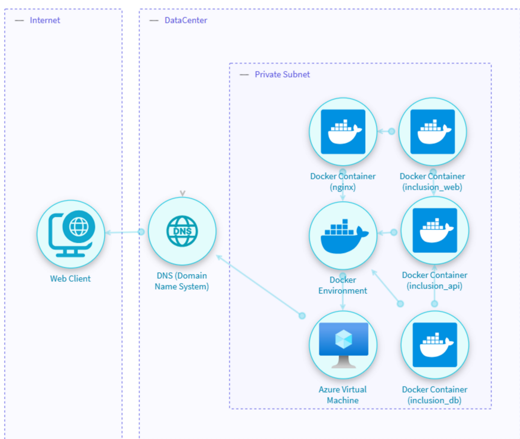

Figure 3. System deployment diagram.

Each URL was evaluated individually using the automated TAW tool. The evaluation focused exclusively on the criteria associated with the perceivability principle, extracting the corresponding results for detected issues, warnings, and elements that could not be automatically verified.

Given that automated tools have limitations when evaluating certain criteria that depend on the context of use and actual interaction with assistive technologies, these findings were considered an initial diagnostic baseline rather than an exhaustive verification of accessibility.

Based on these findings, the accessibility requirements needed to guide the redesign and improvement of the platform were defined, as described in the following section.

2.5. Design of Improvements

Based on the criteria established for AA conformance with the perceivability principle of WCAG 2.1, the functional and non-functional requirements guiding the platform modifications were defined. These requirements were grouped into two categories: general functional accessibility requirements, shown in Table 1, and non-functional requirements, shown in Table 2.

Table 1. Functional accessibility requirements related to perceivability

ID	WCAG Guideline	Description	Priority
REQ-001	1.1.1	Inclusion of meaningful alternative text for images and graphics.	High
REQ-002	1.3.1	Proper use of HTML5 and ARIA semantic labels.	High
REQ-003	1.4.3	Ensure a minimum contrast ratio of 4.5:1 between text and background.	High
REQ-004	1.4.4	Allow text resizing up to 200%, without loss of functionality.	High
REQ-005	1.4.5	Avoid the use of text images, except in exceptional cases.	High

Table 2. Non-functional requirements improving perceivability

ID	Category	Description	Priority
RNF-001	Usability	Ensure accessibility for users with visual impairments.	High
RNF-002	Performance	Maintain optimal load times after modifications.	Medium
RNF-003	Compatibility	Ensure proper functioning with screen readers.	High
RNF-004	Maintainability	Document all adaptations to facilitate future updates.	Medium

Once the requirements had been established, accessible prototypes were designed using the Figma platform, as shown in Figure 4. These prototypes incorporated inclusive design criteria, including:

- the correct semantic hierarchy of content through structured headings;
- institutional colors with sufficient contrast;
- the intuitive interface organization to facilitate assisted navigation;
- the reduction of distracting visual elements to promote simplicity;
- the inclusion of clear and visible labels in forms, buttons, and links.

Likewise, a technical implementation plan was developed in accordance with the RAD methodology. This plan specified:

- the specific tasks to be performed for each affected component;

- the prioritization of interventions according to the severity of the identified barriers;
- the technologies and best practices to be applied, including semantic HTML, ARIA, and accessible CSS;
- the development schedule organized into iterative cycles;
- the technical documentation of each intervention for validation and maintenance purposes.

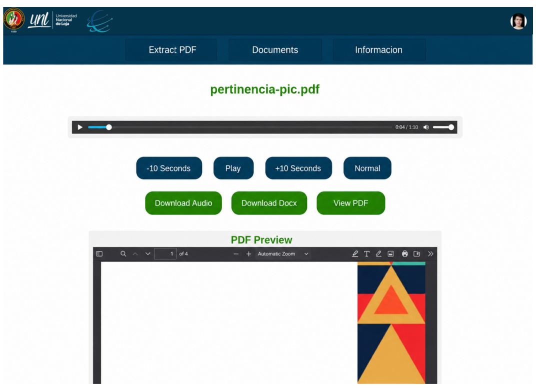

Figure 4. Accessible prototype of a key platform interface designed in Figma.

Additionally, as part of the development and validation process, a technical project repository was used to document the implemented modifications and design decisions, thereby supporting the reproducibility and validation of the results: https://github.com/Yovin001/inclusionLectora

2.6. Technical Implementation

Based on the defined functional and non-functional requirements, the source code of the main pages of the web platform was modified by applying the accessible design principles established in WCAG 2.1, at conformance level AA. The implemented improvements are summarized in Table 3.

To illustrate the impact of the implemented improvements, Figures 5 and 6 compare the original platform interface with the accessible version developed in this study. This comparison highlights changes in color contrast, visual organization, and the clarity of interactive components.

Although the platform's visual interface was not substantially modified, technical adjustments were made to improve its interpretation by assistive technologies. In particular, priority was given to accessible component labeling, semantic structural organization, and the proper definition of names, roles, and descriptions for interactive elements.

One of the most relevant aspects of the intervention was the improvement in accessible labeling for interface elements. Attributes such as aria-label, aria-describedby, along with appropriate semantic associations between labels and form fields, were incorporated to improve screen reader interpretation.

Table 3. Accessibility improvements implemented in the source code

Identified issue	WCAG 2.1 guideline not met	Solution applied
Images without text meaningful alternative text were added	1.1.1 Non-text content.	Descriptive alt attributes or aria-hidden="true" for decorative elements.
Icons without textual alternative	1.1.1 Non-text content.	Dynamic aria-label attributes were added, hidden with aria-hidden="true", or removed if unnecessary.
Use of color without sufficient contrast	1.4.3 Minimum contrast.	Colors in CSS styles were adjusted to achieve a minimum contrast of 4.5:1 in all states.
Buttons or links without accessible labels	4.1.2 Name, function, value.	aria-label attributes were added that clearly describe the function of each button or link.
Form fields without clear semantic relationships.	1.3.1 Information and relationships.	The attributes htmlFor, aria-describedby, and role="alert" were used to associate labels, inputs, and messages.
Headers without structure were reorganized	1.3.1 Information and relationships.	The tags <h1>, <h2>, and <h3> to reflect a clear, semantic hierarchy.
Controls without visible focus	2.4.7 Visible focus.	Custom styles were applied to the :focus state to ensure the focus is visible during keyboard navigation.
Elements defined by color alone	1.4.1 Use of color.	ARIA text or attributes were added that allow the purpose to be interpreted without relying exclusively on color.
Absence of the attribute lang in the document	3.1.1 Page language.	The Spanish language was declared in the root HTML using lang="es" for assistive technologies.
Status messages non-accessible	4.1.3 Status messages.	It was proposed to use role="alert" or aria-live="assertive" in message containers (in some cases, this remained pending).
Audio controls without text alternatives	1.2.1 Audio only (recorded).	It was recommended to add an accessible text transcript for users with hearing impairments.
Removed visual elements due to lack of functionality or accessibility	N/A	Elements that did not contribute and did not meet accessibility criteria were removed from the code.

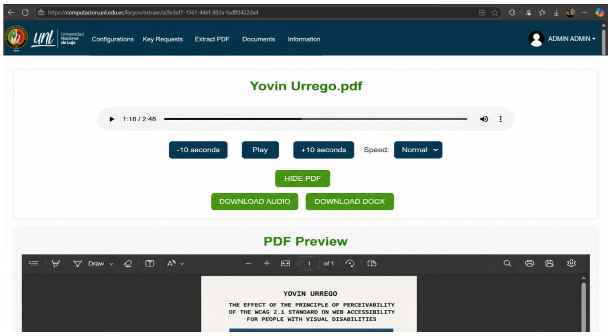

Figure 5. Original interface with accessibility barriers.

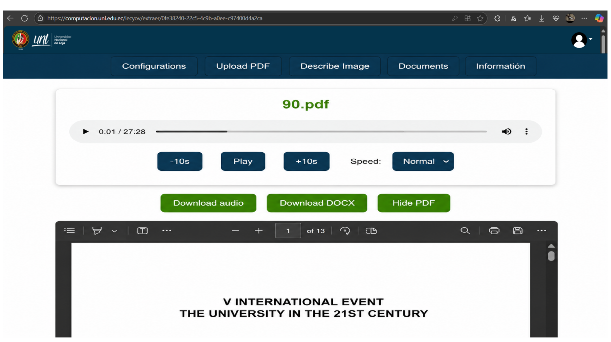

Figure 6. Accessible interface after implementing improvements based on the perceivability principle of WCAG 2.1.

To illustrate these technical changes, Figures 7, 8, and 9 present examples obtained using the browser's accessibility inspector. These captures show improvements in component labeling and accessible structure, enhancing screen reader reading and interpretation.

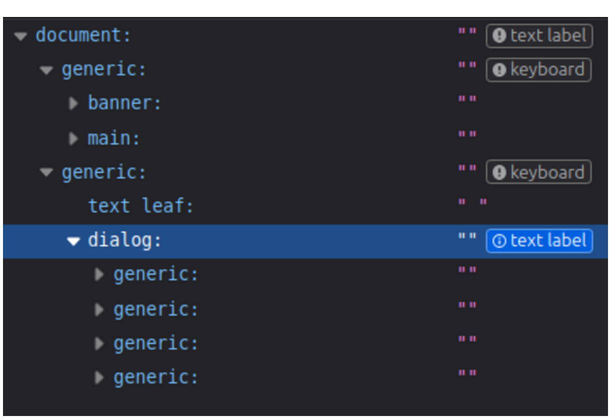

Figure 7. Accessible structure in the original version.

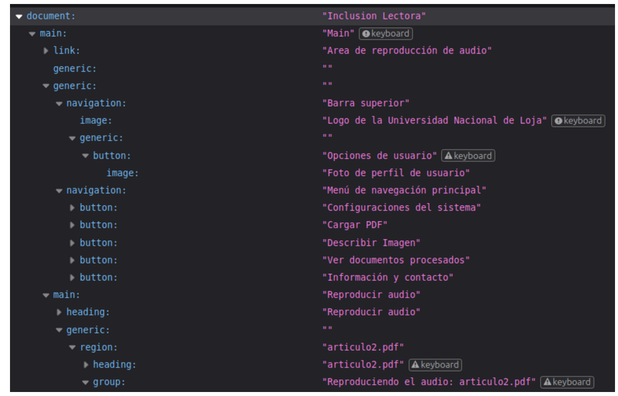

Figure 8. Accessible structure in the improved version (upper section).

Figure 9. Accessible structure in the improved version (lower section).

2.7. Post-Evaluation (Posttest)

To measure the impact of the implemented improvements, a second automated evaluation was conducted using the same methodological approach as in the pretest [13]. A new project branch, named "posttest," was created, incorporating all modifications related to the perceivability principle.

This version was deployed in a testing environment equivalent to the initial one, and the same reference URLs of the platform were reused to ensure comparability of the results.

The TAW tool was used again to analyze each page according to the perceivability criteria. Data were collected on detected issues, warnings, and non-verifiable elements.

Consequently, the posttest results were interpreted together with the manual evaluation and user validation to avoid relying solely on an automated assessment of the level of accessibility achieved.

These results were compared with those obtained in the initial evaluation, allowing the specific effect of the interventions on platform accessibility to be estimated.

2.8. Manual Evaluation

Manual accessibility testing was carried out using the NVDA screen reader to validate compliance with Principle 1, Perceivability, of WCAG 2.1 at conformance level AA. The evaluations focused on key interface components, including form fields, buttons, links, menus, and navigation structures, through actions such as tab navigation, use of arrow keys, keyboard activation, and sequential reading.

To ensure objectivity in the process, an external evaluator outside the development team was included: a university student experienced in using the NVDA screen reader. Her participation made it possible to assess the platform's accessibility from a perspective closer to the real experience of users with visual impairments, identifying barriers that may go unnoticed in a technical self-evaluation [11].

2.9. User Validation

As part of the validation process, an in-person workshop was organized with users with visual impairments at the National University of Loja. Participants were selected based on their experience using assistive technologies, particularly screen readers such as NVDA.

From an initial population of 15 students with visual impairments enrolled in face-to-face programs, four participants were selected for the tests. The selection criteria included availability, prior experience with screen readers, and logistical constraints, such as academic schedule conflicts, mobility difficulties, or technological limitations. From a qualitative perspective, this reduced sample size is justified by the purposive sampling method, which is commonly used in exploratory accessibility studies [14].

Although the sample was small, its selection was consistent with the exploratory nature of the study and its purpose of identifying relevant accessibility barriers during an initial validation stage. In usability and accessibility research, small samples can detect frequent interaction issues when evaluations involve specific tasks and users experienced in assistive technologies. However, this methodological decision limits the inferential scope of the results; therefore, the findings should be interpreted as contextual evidence rather than as a statistical generalization applicable to the entire university population with visual impairments.

Additionally, according to Jakob Nielsen's model, four participants are estimated to be sufficient to identify approximately 75% of the most frequent usability problems. This estimate is based on the following formula:

$$P = N \times (1 - (1 - L)^n) \tag{1}$$

where P represents the detected problems, N the total number of problems, L the probability that a user detects a problem ($L \approx 0.31$), and n the number of evaluated users [15]. As Nielsen argues, even a single user can reveal a considerable proportion of critical issues, and as more users are added, the amount of new information decreases. This rationale supports the use of small samples in early stages, when the objective is to identify and address the most evident barriers.

During the workshop, users performed functional tasks representative of actual platform use, including registration flows, login, PDF file upload, and audio content playback. Each activity was carried out autonomously using the NVDA screen reader. When significant difficulties arose, the development team intervened promptly to allow the exercise to continue.

After participants completed the functional tasks in the first version of the platform, which did not include accessibility improvements, the validation instruments were applied to assess their perception of accessibility. The same process was then repeated with the second version, which had been modified according to the perceivability principle. Finally, a comparative interview was conducted between both versions. All participants completed the tests in both versions of the system, pretest and posttest, allowing for a direct comparison of the user experience under the same experimental conditions.

Instruments applied for the evaluation of accessibility

To evaluate the user experience from both quantitative and qualitative perspectives, the following instruments were designed and applied:

- A Likert-scale survey from 1 to 5, based on criteria associated with the perceivability principle of WCAG 2.1.
- Open-ended questions to collect detailed observations.
- A comparative interview between versions to validate perceived improvements.

Likert-type survey: This instrument assessed perceptions of accessibility in key aspects of the interface, including ease of reading, screen reader use, clarity of instructions, visibility of alerts, and accessibility of controls.

Table 4. Likert-type survey questions

Question	Associated WCAG criterion
Was it easy to perceive all text on the screen?	Text contrast / readability.
Did the screen reader correctly read all elements?	Text alternatives / accessible labels.
Were the instructions clear and perceptible?	Contextual hints / visible instructions.
Were alerts or errors easily perceived?	Audible and visual alerts.
Were buttons, fields, and controls distinguishable and visible when focused?	Visible focus / contrast / keyboard navigation.

Each question was rated on a scale from 1 (strongly disagree) to 5 (strongly agree) and applied separately after the use of each version of the platform.

Open-ended questions: To obtain deeper qualitative feedback, open-ended questions were administered after participants used each version. These questions helped identify perceived barriers, navigation difficulties, and specific suggestions from the user's perspective.

Comparative interview between versions: After the validation of both versions was completed, a comparative interview was conducted to identify perceived differences, observed improvements, and elements still requiring improvement. This activity helped validate the effectiveness of the interventions through a direct comparison of user experience.

Table 5. Open-ended questions for qualitative feedback

Question
Was it easy to read all the text on the screen?
Was there anything you couldn't read clearly in this version?
Which part did you find most difficult to identify or understand?
How would you improve this version?

Table 6. Comparative interview questions between versions

Question
Did you notice any differences between the first and second versions?
Which version was clearer or easier to use with your screen reader?
Where did you notice the biggest difference?
Were the messages, buttons, or alerts easier to perceive in the second version?
What would you improve in the accessible version?

2.10. Results Analysis

The results were analyzed through methodological triangulation, integrating quantitative and qualitative data from three sources: automated evaluation, manual evaluation using a screen reader, and validation with users with visual impairments.

Given the small sample size, the quantitative analysis was approached descriptively, and no inferential tests were performed. The results were interpreted using averages and observed trends between the evaluated versions.

For the automated evaluation, the reports generated by the TAW tool during the pretest and posttest phases were used. The extracted data were organized into comparative matrices for each evaluated page, classifying the findings into three categories: errors, warnings, and non-verifiable elements. Based on these matrices, bar charts were generated to visualize changes between versions, highlighting the reduction or persistence of issues related to the perceivability principle.

For the manual evaluation, the findings reported by the external evaluator during the functional walkthroughs were coded and grouped according to the type of barrier detected, namely visual, structural, or semantic, and the affected component, including forms, navigation, controls, and content. This coding enabled the construction of a barrier map, which was later compared with the implemented improvements.

The qualitative and quantitative data collected during user validation were analyzed at two levels. First, responses to the Likert questionnaires were processed using measures of central tendency, including means and standard deviations, to identify patterns of perception regarding accessibility, comprehension, and navigability. Second, a thematic analysis of the semi-structured interviews and open-ended questions was conducted, organizing the responses into emerging categories related to user experience, identified barriers, and improvement suggestions.

2.11. Ethical Considerations

All user validation activities were conducted in accordance with ethical principles for research involving human subjects. Written informed consent was obtained from all participants, ensuring voluntary participation, confidentiality of the collected data, and anonymity of responses in the dissemination of results.

3. Results and Discussion

3.1. Results of the Automated Evaluations

The initial evaluations identified accessibility barriers related to insufficient color contrast, absence of alternative texts, deficient semantic structures, and forms without descriptive labels.

After the implementation of improvements, the critical errors detected by TAW were reduced to zero on the evaluated pages, as shown in Table 7. The barriers initially identified included the following:

- **Insufficient color contrast,** which hindered readability.
- **Lack of alternative** texts in images and graphical elements.
- **Inadequate semantic structure,** affecting interpretation by assistive technologies.
- **Form-related issues,** such as the absence of descriptive labels.

As shown in Table 7, critical errors classified as "Issues" were completely eliminated, indicating a significant technical improvement. Likewise, warnings were reduced by 44.19%, reflecting progress in labels and descriptions, although these aspects still require further improvement.

The "non-verifiable" elements remained unchanged due to the limitations of automated tools such as TAW, which must be complemented by manual evaluation or user-based validation. These results demonstrate the positive impact of applying the perceivability principle of WCAG 2.1 through iterative approaches, including RAD, contributing to a more accessible web experience for individuals with visual impairments.

Table 7. Comparison of accessibility errors before and after the intervention

Category	Pre-test	Post-test	Reduction
Problems	32	0	100%
Warnings	43	24	44.19%
Unverified elements	40	40	0%

3.2. Results of the Manual Evaluation

The NVDA evaluation revealed several perceptual barriers, including errors in button activation, lack of confirmation for critical actions, incorrect labels, and conflicts between screen reader narration and audio playback. Most of these issues were corrected during the improvement process, as summarized in Table 8, where the main findings are grouped by test case and resolution status.

Table 8. Summary of the manual evaluation results with NVDA

Case test	Identified issues	Status
Login.	Typing errors, disabled button, resizing when displaying warnings.	Resolved
Registration	Incorrect password confirmation prompt, fields accepting letters, incorrect button order.	Partially resolved
Forgotten password	Button disabled with no feedback.	Resolved
Dashboard	The reader does not announce search results or confirm deletion.	Resolved
Player	Narration overlaps between reader and audio.	Unresolved
Extractor	Vague buttons, issues loading files.	Resolved
Global settings.	Unnecessary reading of warnings, incorrect messages when deletion fails.	Resolved
Profile and change password	Incorrect reading of password buttons and non-standard labels.	Resolved
All pages	Missing "skip to content" link and unintuitive order of save/cancel buttons.	Resolved

Manual testing confirmed that most of the initial barriers were eliminated, substantially improving the navigation experience with assistive technologies. However, some aspects requiring future review were identified, particularly in the audio component, where perceptual conflicts persist.

3.3. Results of User Validation

As part of the system accessibility validation process, tests were conducted with four participants with visual impairments, who completed all interaction flows in both versions of the system: the initial version and the accessible version. Subsequently, satisfaction surveys with Likert-type questions were administered, open-ended interviews were conducted to collect qualitative observations, and a comparative interview between versions was carried out to understand participants' overall perceptions.

3.3.1. Results of the Likert-type survey

The results obtained through the Likert scale show a substantial improvement in perceived accessibility in the accessible version of the system. Five key aspects related to the perceivability principle of WCAG 2.1, at conformance level AA, were evaluated: text readability, visibility of buttons and controls, perception of alerts, clarity of instructions, and document reading by the screen reader.

Table 9. Averages obtained for each item in both evaluated versions

Assessment criterion	Pre-test	Post-test
Contrast / text	3.00	4.50
Text alternatives	2.50	4.75
Instructions / contextual hints	2.00	4.75
Visual and auditory alerts	2.50	4.75
Visual focus / contrast / keyboard navigation	2.25	4.50

As shown in Table 9, all evaluated aspects improved significantly after the implementation of accessibility enhancements based on the perceivability principle of WCAG 2.1, at conformance level AA. Specifically, text contrast improved from 3.00 to 4.50; text alternatives from 2.50 to 4.75; instructions and contextual aids from 2.00 to 4.75; visible and auditory alerts from 2.50 to 4.75; visible focus, contrast, and keyboard navigation from 2.25 to 4.50; and proper document reading by the screen reader from 2.00 to 5.00. These results indicate that the implemented interventions were effective in improving interaction through assistive technologies.

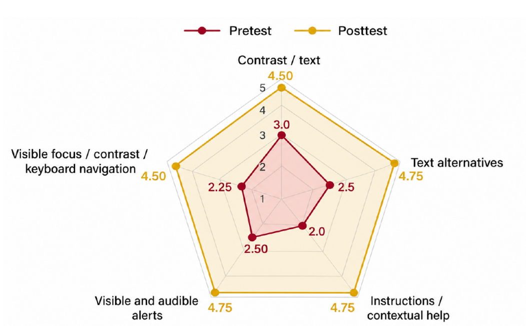

Figure 10. Graphical comparison of scores by evaluated criterion on a scale from 1 to 5.

3.3.2. Results of the open-ended interviews

The open-ended interviews provided a qualitative and detailed perspective on the user experience. The most relevant findings are summarized below, according to the categories of analysis.

Perception of visual elements: In the initial version, users reported difficulties distinguishing certain visual elements. Issues such as buttons with similar colors that did not clearly differentiate their functions, as well as dialogs that were difficult to perceive or poorly structured, were identified. In contrast, users reported a clearer experience in the accessible version, indicating that visual elements were more distinguishable and that the NVDA screen reader correctly interpreted dynamic interface changes, such as pop-up messages and focus transitions.

Comprehension and navigability: Navigation in the first version was confusing, particularly when users tried to identify the player buttons, complete the document upload process, and locate status messages. In the accessible version, these obstacles were notably reduced. Users reported that the organization of content and the screen reader response facilitated a more intuitive understanding of the system.

Suggestions for improvement: Among the suggestions collected, participants proposed incorporating an option to select the starting page for document reading, allowing the upload of .doc files, improving the wording of informational dialogs, and adding functions to jump to specific sections of the content. Several of these recommendations had already been implemented in the evaluated accessible version.

3.3.3. Results of the comparative interview between versions

In the final interview, users were asked to compare both versions of the platform. The responses reflected a clear preference for the accessible version (V2), highlighting substantial improvements in both interface design and compatibility with assistive technologies.

General perception: Users agreed that the accessible version offered a clearer and less confusing experience, with a more organized visual and semantic structure. Improvements in content presentation and a reduction in cognitive load during navigation were also highlighted.

Screen reader compatibility: Users reported smoother and more understandable navigation with the screen reader in the accessible version. Improvements in HTML structure, tab order, and the appropriate use of ARIA labels contributed to more effective interaction.

Areas with the greatest perceived improvement: The elements that showed the greatest improvement were buttons, navigation focus, contextual messages, and informational dialogs. Some users also noted that blank spaces and sections previously omitted by the screen reader could now be correctly identified.

Perception of messages and alerts: System messages, errors, and alerts were more clearly perceived in the accessible version, both visually and through screen reader interpretation. This contributed to a better understanding of system states and required actions.

Additional suggestions: Although the accessible version significantly improved the experience, users suggested continuing to incorporate features aimed at reading personalization, such as the ability to define specific starting points or jump to certain sections to facilitate navigation in long documents.

3.4. Discussion of the Findings

The results indicate that applying the perceivability principle of WCAG 2.1 has a positive and measurable impact on improving web accessibility for individuals with visual impairments in university environments. The technical implementation was based on the level AA criteria of this standard [1], through practices such as semantic tags, alternative attributes, adequate contrast, and ARIA roles, in line with the approaches was proposed by Miranda and Araujo [8] and Manu et al. [4].

First, the automated evaluations conducted using the TAW tool showed the complete elimination of critical errors after the intervention, with a reduction of 100%. This improvement is attributed to the systematic application of accessibility guidelines, particularly in aspects such as text contrast, the inclusion of text descriptions, and clear semantic structure. These results are consistent with previous studies that identify perceivability errors as key factors affecting the experience of users with visual impairments [7], [11], and have also been documented by Henkelmann and Fertig [5].

Likewise, warnings related to labels, descriptions, and relationships between elements were reduced by 44.19%. This result suggests that, although automated tools are useful for identifying perceptual barriers, they have significant limitations when evaluating certain aspects, such as text resizing or auditory feedback. Therefore, they must be complemented by manual evaluations and testing with real users [10], [16].

Manual testing with NVDA confirmed that most of the initial barriers were corrected, including incorrect button reading, focus issues, and lack of feedback. However, difficulties such as overlap between the screen reader voice and the audio player persisted, as also noted by Kerdar et al. [2]. This finding reinforces the idea that some perceptual conflicts cannot be resolved solely through technical adjustments but require a user-centered functional redesign.

The results of the Likert-type survey reflect a substantial improvement in all evaluated aspects, as shown in Table 9. Particularly notable were the increases in button visibility, clarity of instructions, and document reading, which reached the maximum score of 5.0. This finding is consistent with the W3C WAI recommendations [17], which emphasize the importance of ensuring that content is distinguishable and understandable both visually and auditorily to guarantee perceivability.

The qualitative interviews provided deeper insight into the user experience. Participants highlighted improvements in visual organization, element identification, and screen reader interpretation of content. Increased autonomy during navigation was also reported. These perceptions confirm the relationship between accessibility and usability described by Petrie and Kheir [3], as well as the importance of clear auditory feedback, as noted by Henkelmann and Fertig [5] and Laamanen et al. [4].

However, some recommendations provided by users were not strictly related to the perceivability principle, but rather to additional functionalities, such as the ability to select the starting page for reading or facilitate navigation between sections. These observations suggest that comprehensive accessibility should also consider the operability and understandability principles of WCAG 2.1 [1], and that its implementation requires an iterative and participatory approach, as proposed by Miranda and Araujo [8].

Furthermore, from critical perspectives on digital disability, accessibility is not limited to technical compliance; it also involves considering users' real experiences in specific social and technological contexts [18].

Although WCAG 2.1 constitutes a fundamental technical guide for improving web accessibility, compliance alone does not guarantee a fully accessible experience in real academic contexts. Aspects such as the contextual clarity of content, cognitive load during navigation, and interaction with dynamic components cannot always be adequately assessed through normative criteria or automated tools. Therefore, in complex university environments, the application of these guidelines must be complemented by manual evaluations, user validation, and a user-centered approach focused on real experiences of individuals with visual impairments.

However, the results should be interpreted with caution. Although significant improvements in perceived accessibility were evident, they were evaluated in a controlled context and with a limited sample, which restricts their generalization. Additionally, some aspects of accessibility, such as interaction with dynamic components and the management of multimedia content, remain challenging and were not fully addressed in this study. Future work could therefore expand the analysis by incorporating other WCAG 2.1 principles and conducting evaluations in more diverse usage contexts.

In summary, the implementation of the perceivability principle significantly improved accessibility for individuals with visual impairments, from both a technical and a user-experience perspective. These findings provide an affirmative answer to the research question by demonstrating that the improvements not only contributed to regulatory compliance but also had a clear effect on user interaction, comprehension, and autonomy. Consequently, the study confirms that effective accessibility in university contexts requires not only technical adjustments but also continuous evaluation processes focused on real experiences of individuals with visual impairments.

4. Conclusions

The application of the perceivability principle of WCAG 2.1, at conformance level AA, had a significant impact on improving the accessibility of a university web platform for individuals with visual impairments by facilitating system comprehension, navigation, and autonomous use. The results obtained in this study showed increases of more than two points across all indicators of the Likert-type survey, with scores exceeding 4.4 out of 5, compared with the original version, whose scores did not exceed 2.5. These improvements were reflected in the complete elimination of critical errors detected through automated evaluation and in users' clear preference for the accessible version. Collectively, these findings demonstrate that the proper implementation of the perceivability principle has a positive effect on both the technical quality of the platform and the user experience.

The use of the RAD methodology enabled the application of the perceivability principle, facilitating the correction of previously identified accessibility deficiencies, such as the absence of textual alternatives, inadequate color contrast, incorrect use of labels, and insufficient semantic hierarchy. To address these deficiencies, technical solutions were incorporated, including aria-label attributes, alt tags in images, HTML5 structural elements, and CSS stylesheet adjustments to ensure visible focus and keyboard navigation.

The evaluations conducted with users confirmed a smoother experience, characterized by clearer feedback and greater compatibility with screen readers. The accessible version was rated as significantly more usable and understandable, reinforcing the effectiveness of applying the perceivability principle of WCAG 2.1 through a process that integrated automated evaluation, manual testing, and user validation.

The application of the perceivability principle in a university web platform for individuals with visual impairments enabled the creation of a digital environment that not only improves technical compliance with the criteria associated with WCAG 2.1 but also substantially enhances the experience of these users.

The combination of an agile methodology, specific technical interventions, and validation with end users supported compliance with accessibility requirements and contributed to a more inclusive, clear, and efficient experience, thereby improving the quality and usability of the university web platform for individuals with visual impairments.

Limitations of the Study

The study presents some limitations that should be considered when interpreting the results. First, the sample size was small, which is consistent with the exploratory nature of the research but limits the generalization of the findings to other populations.

Second, the same participants evaluated both versions of the system, pretest and posttest, which could introduce a learning bias that may influence the perceived improvement.

Likewise, the use of automated tools such as TAW presents inherent limitations, as these tools do not allow for a comprehensive evaluation of aspects related to user experience, contextual understanding of content, or interaction with assistive technologies.

Finally, the study focused solely on the perceivability principle ofWCAG 2.1; therefore, the principles of operability, understandability, and robustness were not comprehensively evaluated.

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Contributor Role

- **Francisco Álvarez-Pineda:** Conceptualization, data curation, formal analysis, research, methodology, project management, supervision, validation, visualization, writing – review and editing.
- **Yovin Urrego-Gómez:** Conceptualization, data curation, formal analysis, research, methodology, software, validation, visualization, writing – original draft.
- **Pablo Ordóñez-Ordóñez:** Conceptualization, validation, visualization, writing – review and editing.
- **Hernán Torres-Carrión:** Conceptualization, validation, visualization, writing – revision and editing.

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