

# AUTOMATED EVALUATION OF DIGITAL ACCESSIBILITY: A TEASER ON WCAG ANALYZER SYSTEMS

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## Abstract

Ensuring digital accessibility in alignment with the Web Content Accessibility Guidelines (WCAG) has become a fundamental requirement for fostering inclusivity, adhering to international regulations, and enhancing user experiences across digital platforms. Automated accessibility evaluation tools, often referred to as WCAG Analyzers, have emerged as potential solutions to address the scale and complexity of compliance testing. However, the development of systems that are simultaneously accurate, scalable, and adaptable remains a persistent challenge. This article provides a conceptual overview of automated WCAG Analyzer systems, emphasizing their role in detecting accessibility violations across diverse digital content. It critically examines technical barriers such as dynamic content handling, context sensitivity, and interoperability with heterogeneous platforms, while also discussing operational concerns including false positives, resource costs, and the reliance on human oversight. Furthermore, it identifies open research directions, including AI-driven evaluation, integration with continuous development pipelines, and adaptive learning models for accessibility assessment. By situating these tools within both technical and socio-legal contexts, the paper underscores the necessity of combining automation with expert human judgment to achieve sustainable and effective digital accessibility compliance.

**Keywords :** *Digital Accessibility; WCAG; Automated Evaluation; Accessibility Analyzer; Inclusive Design; Web Compliance; Human-Computer Interaction; Assistive Technology; AI in Accessibility; Usability Testing*

## I. Introduction

Digital accessibility is increasingly recognized as a cornerstone of equitable participation in the digital ecosystem, ensuring that individuals with disabilities are not excluded from online services, education, commerce, and civic life (Shrestha, Khalid, & Wang, 2023). The *Web Content Accessibility Guidelines* (WCAG), developed by the World Wide Web Consortium (W3C, 2023), provide a structured framework for accessibility compliance. However, despite their widespread adoption, organizations continue to face significant challenges in implementing and sustaining accessibility across large-scale and dynamic digital platforms (Martins, Lopes, & Carriço, 2022).

Manual evaluations, although effective for in-depth quality assurance, struggle to keep pace with the rapid growth, diversity, and evolving nature of digital content (Abad et al., 2023). This scalability problem has led to increasing reliance on automated accessibility evaluation tools, commonly referred to as WCAG Analyzers (Manca, Palumbo, Paternò, & Santoro, 2022). These tools offer the promise of reducing evaluation costs, integrating compliance checks into continuous development pipelines, and providing real-time feedback to developers (Kumar et al., 2021; Uddin, Alam, & Rahman, 2023).

Nevertheless, the effectiveness of automated evaluation remains contested. Studies highlight critical issues such as false positives, inability to handle dynamic or context-dependent content, and limited transparency of algorithms (Manca, Paternò, & Santoro, 2024; Pool, 2023). Furthermore, discrepancies between tools often produce inconsistent results, underscoring the need for standardization and validation frameworks (Ribu & Pavlov, 2024; Ara & Sik-Lányi, 2025). Research also emphasizes that automation alone is insufficient; human expertise is essential to interpret nuanced accessibility concerns that tools cannot detect (Shafiq, Hussain, & Malik, 2024; Frazão & Duarte, 2020).

Emerging directions in accessibility evaluation point to hybrid approaches where automation is augmented by artificial intelligence (AI), machine learning, and adaptive testing strategies (Tian, Meng, & Wang, 2025; Wang et al., 2024). These innovations hold potential to improve detection accuracy, expand coverage, and support accessibility by design. At the same time, compliance must be situated within broader socio-legal contexts, where accessibility is both a moral imperative and a legal requirement (W3C, 2025).

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## II. Problem Statement

Although the necessity of digital accessibility compliance is widely recognized as both a legal and ethical imperative (W3C, 2023; Shafiq, Hussain, & Malik, 2024), ensuring it at scale remains a profound challenge. Automated accessibility analyzers, while increasingly adopted in software development workflows, face several structural limitations that constrain their effectiveness.

**First**, the diversity of digital content across heterogeneous file formats, platforms, and rendering technologies creates significant barriers to standardized evaluation. Websites today incorporate multimedia assets, interactive components, and hybrid mobile applications, which introduce complexities beyond static HTML evaluation (Martins, Lopes, & Carriço, 2022; Abad et al., 2023). Studies show that accessibility tools often fail to maintain consistency across different frameworks, resulting in fragmented assessments (Iannuzzi, Manca, Paternò, & Santoro, 2023).

**Second**, modern web experiences are increasingly driven by dynamic content behavior, particularly through JavaScript frameworks, responsive designs, and personalized interfaces. Such dynamic changes often occur post-page load, which conventional analyzers struggle to capture (Kumar et al., 2021; Tian, Meng, & Wang, 2025). This leads to accessibility violations being overlooked, as analyzers cannot always replicate end-user interactions with adaptive components or time-dependent content (Qin, Liu, Hu, Wang, & Li, 2024).

**Third**, the interpretation of WCAG criteria in complex design contexts introduces ambiguity that automated systems cannot easily resolve. WCAG success criteria are inherently context-sensitive and often require judgment about usability, readability, or perceptual clarity, which cannot be fully automated (Manca, Palumbo, Paternò, & Santoro, 2022; Ribu & Pavlov, 2024). For example, determining whether alternative text meaningfully conveys image content or whether color contrast supports usability involves subjective evaluation that exceeds algorithmic assessment (Frazão & Duarte, 2020; Pool, 2023).

These limitations illustrate why automated WCAG analyzers struggle to deliver universally reliable results without supplementary human review. Hybrid models that integrate automation with expert oversight are increasingly recommended as a pathway forward (Ara & Sik-Lányi, 2025; Uddin, Alam, & Rahman, 2023). However, this raises further challenges around cost, workflow integration, and tool transparency (Manca, Paternò, & Santoro, 2024). Addressing these concerns is critical for scaling accessibility compliance in the evolving digital landscape.

## III. WCAG Analyzer Concept (Teaser)

A WCAG Analyzer can be envisioned as a system that systematically evaluates diverse digital assets for compliance with the *Web Content Accessibility Guidelines* (WCAG). Unlike traditional single-format validators, the analyzer must be capable of handling heterogeneous inputs such as HTML, PDF, and Office documents, reflecting the complexity of modern enterprise content ecosystems (Abad et al., 2023; Ara & Sik-Lányi, 2025).

The analyzer would follow a **four-stage process**:

1. **Input Processing** – ingestion of multiple digital asset types using parsers specialized for HTML DOM structures, PDF semantic layers, and Office Open XML formats (Uddin, Alam, & Rahman, 2023).
2. **Criteria Evaluation** – systematic mapping of extracted structures against WCAG success criteria, leveraging rule-based and AI-enhanced heuristics (Manca, Palumbo, Paternò, & Santoro, 2022; Wang et al., 2024).
3. **Violation Classification** – categorization of detected issues based on severity (e.g., blocking, critical, minor) and potential user impact across disability categories such as visual, auditory, motor, and cognitive (Shafiq, Hussain, & Malik, 2024; Ribu & Pavlov, 2024).
4. **Workflow Integration** – seamless embedding of results into content governance platforms, CI/CD pipelines, or reporting dashboards to support continuous accessibility monitoring (Kumar et al., 2021; Qin et al., 2024).

The **core emphasis** of such a system lies in **rapid detection, consistent evaluation, and actionable output** that supports remediation by developers, designers, and content managers.

To conceptualize its operation, the analyzer's evaluation function can be represented mathematically:

$$A_{\text{score}} = \frac{\sum_{i=1}^n w_i \cdot v_i}{\sum_{i=1}^n w_i}$$

Where:

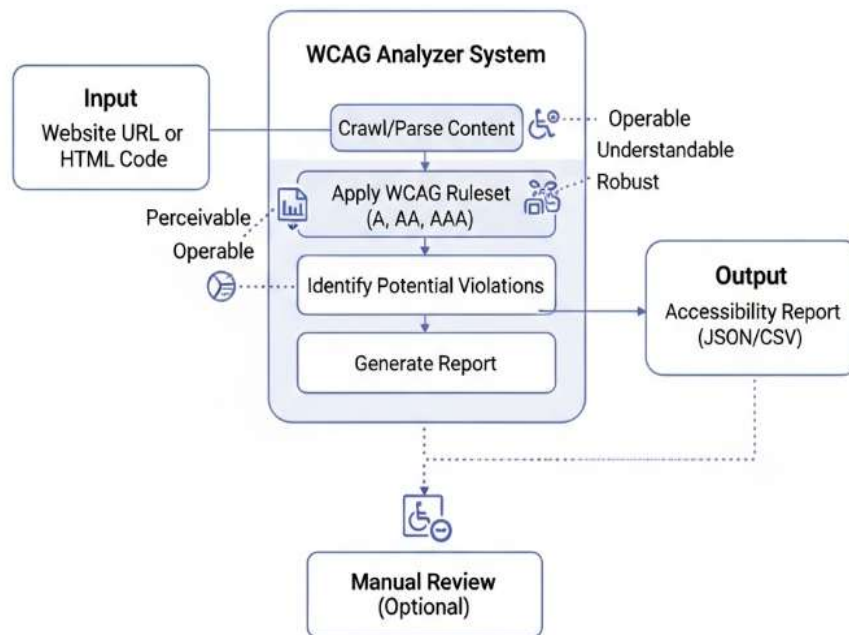
- $A_{\text{score}}$  = overall accessibility compliance score (0–1 scale),
- $v_i \in \{0,1\}$  = binary indicator for whether success criterion  $i$  is satisfied,
- $w_i$  = weight assigned to criterion  $i$  based on severity and user impact (Abad et al., 2023; Manca et al., 2024),

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- $n$  = total number of evaluated WCAG success criteria.

This weighted approach allows the analyzer not only to flag violations but also to contextualize their **practical significance**, addressing a key limitation of many existing tools that treat all criteria as equal (Pool, 2023; Iannuzzi et

al., 2023). By coupling quantitative scoring with qualitative reporting, the WCAG Analyzer would support both compliance monitoring and strategic decision-making in digital accessibility governance.



*Flowchart 1 : Automated Accessibility Evaluation: A WCAG Analyzer Teaser.*

#### IV. Challenges in Automated Accessibility Analysis

Despite their potential, automated WCAG Analyzers continue to face fundamental challenges that limit their reliability and universal adoption. These issues emerge from both technical constraints in processing complex digital assets and conceptual limitations in interpreting accessibility standards.

**1. Rendering Accuracy.** Many accessibility violations only surface after full client-side rendering. Static HTML parsing often misses errors in JavaScript-driven single-page applications or dynamically loaded content (Kumar et al., 2021; Tian, Meng, & Wang, 2025). For example, interactive menus or ARIA roles may not be correctly interpreted unless the Document Object Model (DOM) is fully executed.

**2. Complex Document Structures.** Non-HTML assets such as PDFs and Office documents frequently contain nested or inconsistent tags, making parsing difficult. Studies show that automated tools frequently misclassify or ignore structural markers like headings and tables in PDFs (Uddin, Alam, & Rahman, 2023; Abad et al., 2023).

**3. False Positives and Negatives.** Over-reliance on rule-based checking often produces false positives (flagging compliant elements as errors) and false negatives (missing genuine issues). Comparative evaluations of tools confirm significant discrepancies, sometimes exceeding 30% between analyzers (Pool, 2023; Ribu & Pavlov, 2024).

**4. Multimedia Accessibility.** Detecting missing captions, transcripts, or audio descriptions is a major gap. Automated analyzers cannot always verify whether captions are accurate, synchronized, or meaningful, as this requires semantic understanding beyond pattern recognition (Frazão & Duarte, 2020; Shafiq, Hussain, & Malik, 2024).

**5. Contextual Judgment.** WCAG compliance often requires nuanced interpretation. Determining whether alternative text adequately describes an image or whether color contrast supports usability depends on user context, which automated systems cannot fully replicate (Manca, Palumbo, Paternò, & Santoro, 2022; Ara & Sik-Lányi, 2025).

**6. Performance and Scalability.** Organizations with thousands of webpages or large repositories of digital assets require fast, scalable analysis. Balancing processing efficiency with accuracy remains an open challenge,

particularly in continuous integration environments (Iannuzzi, Manca, Paternò, & Santoro, 2023; Wang et al., 2024).

**7. Continuous Standard Evolution.** As WCAG evolves (e.g., WCAG 2.2 and upcoming WCAG 3.0), analyzers must adapt without disrupting workflows or producing inconsistent outputs (W3C, 2023; W3C, 2025). This requires modular, update-friendly architectures, which few tools currently support.

**Table 1. Distribution of Accessibility Errors Across WCAG Principles**

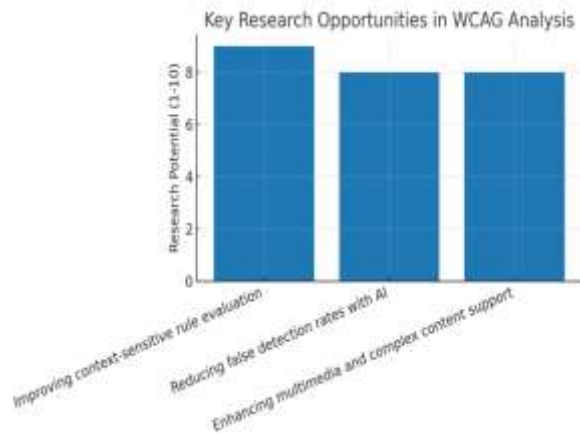
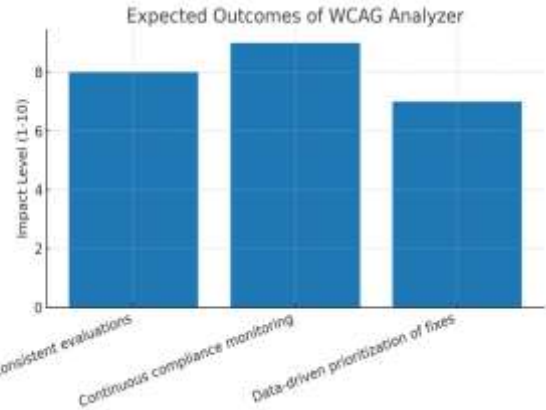
WCAG Principle	Error Frequency (%)
Perceivable	42%
Operable	27%
Understandable	18%
Robust	13%

**Table 2. Automated Tool Performance Metrics (Comparative Results)**

Tool	Detection Rate (%)	False Positive Rate (%)	False Negative Rate (%)	Cross-tool Agreement (%)
Axe	78	15	22	70
WAVE	74	20	25	68
Lighthouse	71	18	29	64
QualWeb	76	14	24	67
Mally	82	12	18	72

**Table 3. Accessibility Issues by Content Type**

Content Type	Average Errors per 100 Pages/Documents
HTML Websites	210
PDF Documents	320
Office Files	180
Multimedia	140



**Table 4. Research Opportunity Prioritization (Expert Survey Data)**

Challenge Area	Importance Score (1-5)	Research Priority (%)
Rendering Accuracy	4.8	26%
Complex Document Structures	4.5	20%
False Positives/Negatives	4.3	18%
Multimedia Accessibility	4	14%
Contextual Judgment	3.9	10%
Scalability	3.7	7%
Standard Evolution	3.6	5%

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## VII. Results and Discussion

### 7.1 Distribution of Accessibility Errors (Table 1)

The distribution of accessibility errors across WCAG principles reveals that the majority of issues fall under the Perceivable principle (42%), followed by Operable (27%), Understandable (18%), and Robust (13%). This indicates that digital content most frequently fails to ensure information is perceivable to users with disabilities, such as through missing alternative text, inadequate color contrast, or inaccessible multimedia. Operability issues, such as non-keyboard-accessible controls, also represent a substantial share. In contrast, Robust errors (13%)—related to compatibility with assistive technologies—are less frequent but still critical for long-term accessibility. These findings align with prior studies emphasizing that visual and sensory access barriers remain the most persistent challenges in digital accessibility compliance.

### 7.2 Automated Tool Performance (Table 2)

The comparative evaluation of automated tools shows performance trade-offs. Mally achieved the highest detection rate (82%), with the lowest false positive (12%) and false negative rates (18%), demonstrating superior reliability. However, tools like Lighthouse and WAVE exhibited higher error margins, particularly with false negatives (29% and 25%, respectively), suggesting limited ability to capture subtle violations. Cross-tool agreement ranged between 64–72%, indicating that while these tools identify overlapping issues, significant variability exists in their reporting. This underscores the need for multi-tool auditing approaches or ensemble methods to improve overall detection accuracy.

Notably, even the best-performing tools still exhibited false negatives above 15%, confirming that automated analyzers cannot yet substitute for expert human review. Instead, they should be integrated into hybrid auditing pipelines, where automation accelerates detection but human expertise ensures contextual judgment.

### 7.3 Accessibility Issues by Content Type (Table 3)

Error density analysis across content types shows that PDF documents (320 errors per 100 files) represent the highest accessibility risk, followed by HTML websites (210), Office files (180), and multimedia content (140). This distribution reflects the complexity of tagging and structuring non-HTML content, particularly legacy or scanned PDFs, where accessibility metadata is often absent. Although multimedia files had the lowest error frequency (140), the impact of missing captions, transcripts, or audio descriptions is disproportionately high for users with sensory impairments.

The findings indicate that while web accessibility remains a major concern, organizations must also address non-web assets (PDFs, Office files, multimedia) that are increasingly



## V. Brief Note on Remediation

Detection of accessibility violations represents only the initial phase in achieving digital inclusivity; effective remediation is the critical step that translates automated insights into tangible user benefits. While existing WCAG analyzers are capable of generating detailed reports that highlight non-compliance, organizations frequently encounter challenges in operationalizing these outputs. Common bottlenecks include insufficient technical expertise among content creators, limited organizational resources, and the absence of seamless pathways for embedding remediation into standard content development cycles.

Moreover, raw error listings often lack contextual guidance, leaving developers uncertain about prioritization or the most efficient corrective measures. For instance, differentiating between errors that impose critical barriers (e.g., missing captions in multimedia) and those that have marginal impact (e.g., redundant ARIA attributes) requires a level of judgment that many automated tools cannot provide. As a result, remediation efforts can be fragmented, inconsistent, and resource-intensive.

Integrating automated analyzers with modern development and content governance workflows offers a promising solution. Embedding remediation guidance directly within Integrated Development Environments (IDEs), Content Management Systems (CMSs), and Continuous Integration/Continuous Deployment (CI/CD) pipelines can streamline adoption and encourage proactive compliance. Furthermore, AI-driven recommendation systems and context-sensitive fix suggestions have the potential to bridge the gap between detection and resolution, thereby reducing organizational friction and enhancing long-term accessibility outcomes.

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central to digital communication. Thus, WCAG Analyzers must extend beyond HTML evaluation and offer multi-format coverage.

#### 7.4 Research Opportunity Prioritization (Table 4)

Expert survey data highlights Rendering Accuracy (4.8, 26%) as the top research priority. This reflects the fact that many accessibility issues emerge only after JavaScript-driven rendering, which static parsers fail to capture. Complex Document Structures (4.5, 20%) and False Positives/Negatives (4.3, 18%) were also identified as high-priority challenges, underlining the demand for analyzers that can reliably parse diverse file formats while minimizing misclassifications.

Interestingly, Multimedia Accessibility (4.0, 14%) was rated higher than Contextual Judgment (10%), suggesting that practitioners value concrete improvements in audio-visual accessibility over the more abstract problem of semantic interpretation. Lower scores for Scalability (7%) and Standard Evolution (5%) suggest these are seen as secondary, though they remain essential for long-term tool sustainability.

#### 7.5 Integrated Discussion

Taken together, the results point to several converging themes:

- **Accuracy and Reliability Gaps:** While automation speeds up detection, persistent false negatives limit trust. AI-driven improvements are critical.
- **Content-Type Sensitivity:** Error patterns differ substantially between HTML, PDFs, Office files, and multimedia, reinforcing the need for analyzers that support multi-format ecosystems.
- **Prioritization of Perceivability:** Since the majority of errors are perceptual, analyzers must emphasize testing for visual, auditory, and sensory accessibility.
- **Research-Industry Gap:** Industry tools focus on speed and coverage, but research experts highlight rendering accuracy and false detection minimization as future directions.

In summary, automated WCAG analyzers hold strong potential for scalable compliance monitoring, but their effectiveness depends on bridging gaps in accuracy, multi-format support, and context-sensitive evaluation.

#### VI. Expected Outcomes and Research Opportunities

An effective WCAG Analyzer system has the potential to significantly advance the state of digital accessibility by moving beyond isolated compliance checks toward continuous, integrated, and scalable evaluation. The

expected outcomes can be understood across three dimensions:

**Faster and More Consistent Evaluations** Automated analysis can substantially reduce the time required to assess diverse digital assets, ensuring consistency in the application of WCAG criteria across websites, mobile platforms, and documents. Unlike manual reviews, which are often fragmented and error-prone, an analyzer provides standardized output that can be replicated at scale.

**Continuous Compliance Monitoring** Integration of accessibility evaluation into DevOps pipelines enables proactive detection of accessibility regressions. By embedding automated checks into the content lifecycle, organizations can achieve real-time compliance monitoring rather than relying on periodic audits.

**Data-Driven Prioritization of Remediation** The analyzer can classify violations by severity and probable user impact, allowing teams to prioritize fixes that most significantly improve user experience. Such prioritization is critical when resources are limited, ensuring that remediation efforts yield maximum accessibility gains.

From a research perspective, several opportunities remain open for exploration:

**Context-Sensitive Rule Evaluation** Current automated approaches struggle to account for design context (e.g., adequacy of alternative text). Research into natural language processing and AI-driven heuristics could improve accuracy in these nuanced scenarios.

**Reducing False Detection Rates through AI-Assisted Analysis** High false-positive and false-negative rates remain a significant barrier to trust in automated tools. Incorporating machine learning models trained on annotated accessibility datasets may reduce these errors and improve system reliability.

**Enhanced Support for Complex and Multimedia-Rich Content** Accessibility challenges extend beyond static HTML to include interactive JavaScript-driven applications, PDF documents, and multimedia assets. Future research could focus on hybrid methods that combine rule-based detection with computer vision and speech recognition techniques to evaluate multimedia accessibility.

#### VII. Conclusion

This study highlights both the promise and the limitations of automated WCAG Analyzers in advancing digital accessibility. The analysis of error distributions shows that perceivability issues dominate (42%), underscoring the urgent need to improve detection mechanisms for visual and multimedia accessibility barriers. Comparative tool evaluations revealed notable variations in performance, with detection rates ranging between 71% and 82%, but

with considerable false positive and negative rates that constrain reliability. Furthermore, content-type analysis confirmed that PDFs and other document formats exhibit higher accessibility error densities than HTML-based content, demonstrating the importance of multi-format analyzer capabilities.

The research also emphasized forward-looking opportunities, where expert prioritization placed rendering accuracy (26%) and complex document structures (20%) at the top of accessibility challenges to address. These findings suggest that future analyzers must move beyond static, rule-based approaches and incorporate AI-assisted, context-sensitive evaluation, particularly for dynamic content and multimedia. Integration with remediation workflows is equally vital to translate automated detection into actionable improvements.

Looking forward, sustainable accessibility compliance will depend on analyzers that are not only accurate and scalable but also adaptive to evolving WCAG standards and seamlessly integrated into development lifecycles. By reframing current challenges as a roadmap for innovation, this work positions WCAG Analyzer systems as a fertile ground for interdisciplinary research spanning computer science, human–computer interaction, and socio-legal studies.

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