VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

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**RESEARCH ON WEBSITE ACCESSIBILITY COMPLIANCE**

Master ‘s degree Thesis

Information Systems Software Engineering study programme, state code 6211BX017

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ specialisation

Informatics Engineering study field

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Vilnius, 2025

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**Abbreviations**

The abbreviations used in this document are described as follows:

* **WCAG**: Web Content Accessibility Guidelines
* **W3C**: World Wide Web Consortium
* **WSREB**: Web System for Responsive and Enhanced Browsing
* **AMS**: Accessibility Monitoring Systems
* **AA**: Conformance Level AA (WCAG)
* **AAA**: Conformance Level AAA (WCAG)
* **SUS**: System Usability Scale
* **WAVE**: Web Accessibility Evaluation Tool
* **AI**: Artificial Intelligence
* **CER**: Coverage Error Ratio
* **WAA**: Web Accessibility Accuracy
* **BU**: Blind User
* **API**: Application Programming Interface
* **ANOVA**: Analysis of Variance
* **UNED**: Universidad Nacional de Educación a Distancia (National Distance Education University)

# Introduction

Web accessibility is a must in today's technological world, so that all users, including people with disabilities, can equally have access to information. The Web Content Accessibility Guidelines are a set of guidelines developed by the World Wide Web Consortium (W3C). These guidelines give very detailed instructions on how to develop accessible websites. Despite these ideals, evidence is overwhelming that the extent of actual accessibility remains an ongoing concern, in many venues including academic library sites and commercial websites. For example, Zare et al. (2021) determined that main library homepages of Iranian institutions did not sufficiently meet accessibility standards of WCAG 2.1. As a consequence, access to digital publications becomes tough for a large number of users with disabilities. The results emphasize the pressing necessity of addressing accessibility challenges, as non-compliance has the potential to block digital access and worsen existing inequalities.

Efforts to improve web accessibility have been innovative in their solutions and learning strategies. In 2023, Naseer et al. came up with the Web System for Responsive and Enhanced Browsing (WSREB) mechanism, an approach allowing for non-linear navigation of web content. The proposed method supports users with visual impairment to overcome the cognitive difficulties in linear navigation. Moreover, the technique further suggests that a multi-factor-based user-centered design will improve accessibility and usability. Chatziemmanouil and Katsanos (2024) prepare a similar approach by establishing the Accessibility Academy, an engaging platform aimed at instructing web developers on compliance with WCAG 2.1 through hands-on tasks. Initiatives to improve web accessibility highlight the essential relationship between technology, education, and policy.

This thesis will explore the level of compliance with accessibility on different websites by determining the level at which the platforms meet the Web Content Accessibility Guidelines. The purpose is to encourage development that will help create more inclusive digital spaces for people with disabilities, analyzing current gaps, exploring new frameworks such as WSREB, and examining educational resources like the Accessibility Academy. Ensuring the Web is an accessible, global platform for all people, regardless of abilities, is both a technological challenge and an ethical imperative. These guidelines help build a good foundation for making user-friendly, accessible websites.

## Investigation Object

Investigation object of this research will therefore be based on the strategies and tools used in assessing website accessibility in accordance with the requirements of the Web Content Accessibility Guidelines (WCAG). These guidelines, developed by the World Wide Web Consortium (W3C), serve as a benchmark for the assessment of the accessibility and usability of digital platforms for people with disabilities. Evaluation procedures usually include both human methods and automated tools, such as the Web Accessibility Evaluation Tool, complemented by expert evaluations, user testing, and assistive technologies like screen readers. Automated methods are used to efficiently identify core compliance problems. On the other hand, manual testing is very important in catching subtle usability issues that might not be detected through automated methods (Zare et al., 2021).

## The Aim and Tasks of the Thesis

The Aim of the Research is to refine the methodologies and procedures for assessing and improving website accessibility in accordance with WCAG requirements.

1. To analyze and compare existing web accessibility evaluation tools and methods.

2. To propose an improved approach for evaluating and ensuring accessibility compliance.

3. To develop and test a prototype tool implementing the proposed approach.

## Novelty of the Topic

The standards of accessibility are very important in the view of increasing digitization of services and the need to ensure inclusion for all people, especially people with disabilities. This is an area still inefficiently explored, particularly in the creation and application of new tools and frameworks that enhance compliance with evolving standards like WCAG 2.1. Numerous recent studies, including those cited in the paper, focus on specific areas like healthcare or education; still, there is a noticeable lack of large-scale cross-sector studies. The solution proposed addresses the limitations of automated evaluation techniques, which often disregard complex issues, such as semantic and context-dependent obstacles to accessibility (Brajnik et al., 2004). The combination of automated tools with manual and user-centered methodologies is a new trend that needs more investigation (Dongaonkar & Vadali, 2017). Including accessibility features at the design stage, rather than trying to rearrange them as an afterthought, is a more sophisticated strategy for ensuring standards are met and accessibility is fostered. The WSREB model, which was especially developed for the visually impaired, is among the creative solutions focusing on this problem, but it did not reach a wider acceptance (Pankowska et al., 2020). Further, differences in adherence to accessibility guidelines, as seen in studies from Latin America and on China, depict the weaknesses in global implementation approaches (Tsaktsiras & Katsanos, 2023; Ceaparu & Shneiderman, 2002). An investigation into the combination of web accessibility and emerging technologies such as artificial intelligence uncovers unexplored potential for innovation. This research enhances both theoretical comprehension and practical execution of accessibility adherence through the examination of diverse fields.

## Relevance of the Topic

Adherence to website accessibility standards is gaining importance because of legal requirements and social movements supporting diversity and fairness. The implementation of guidelines, such as WCAG 2.1, by governmental bodies and corporations across the world reflects its importance within digital policy frameworks (Web Content Accessibility rules 2.0, 2024). Accessibility thus acts as a very important enabler of digital inclusion, whereby people with disabilities can actively participate in all aspects of educational, professional, and social spheres. The research is of high relevance because it presents some of the issues that the marginalised groups face, especially those dependent on assistive technologies (Ismail & Kuppusamy, 2018). It has been during and after the COVID-19 pandemic, with an exponential rise in e-services, that accessibility standards have come under serious consideration for sectors like healthcare and education, whereby access to digital services impacts the delivery of service (Mañez-Carvajal & Cervera-Mérida, 2021). Despite awareness, many websites in both the public and private sectors do not meet the basic requirements for accessibility, highlighting the critical need for comprehensive assessment frameworks (Kous, K & Pavlinek, M, 2020). This presents an economic concern, as websites designed to be user-friendly provide better access for all users, enhancing their engagement and retention levels among consumers. Moreover, accessibility compliance corresponds with international initiatives aimed at reducing inequality, as specified in the United Nations' Sustainable Development Goals. Addressing these challenges through comprehensive research will not only be helpful for people with disabilities but also enhance the overall quality and usefulness of digital platforms for broader audiences. The interdisciplinary nature of the subject, at the merge of computer science, design, and social justice, makes it especially relevant in today's digital world. As the digital environment evolves, accessibility compliance will be a major factor in fair and sustainable technology advancement.

## Research Methodology

Analytical methods and comparative research have been used to review existing website accessibility evaluation tools, methods for measuring WCAG compliance, and design tools. The research generalization, logical induction, and conceptual modeling methodologies have been used to generalize existing techniques and propose an improved framework for the evaluation of website accessibility compliance. Experimental research methodology has been followed to validate the proposed technique and verify its effectiveness on real-life websites.

## Scientific Value of the Thesis

The scientific value of the thesis lies in addressing the ongoing and changing challenges of web accessibility compliance, particularly through new assessment methods. Automated technologies, while effective, can overlook detailed accessibility issues such as meaning-related barriers and user experience challenges, requiring a complete approach that includes manual checks and user feedback (Brajniket al., 2004). Moreover, the research findings will provide practical recommendations for improving compliance, encouraging inclusion, and improving the experience for people with disabilities, thus helping to advance accessibility science and fairness in the digital world.

## Main Results of the Thesis

The analysis of web accessibility evaluation tools, including WAVE, SiteImprove, and TAW, it was found that these automated tools are quite good at catching the common problems: missing alternative text, insufficiencies in contrast ratio, navigation components without accessibility. However, they are limited in depending on pre-defined rules and hence lack the ability to capture complex semantic and context-dependent accessibility issues—like dynamic content not being well labelled for assistive technologies or logical structure of content is not verified properly. Similarly, Burkard, Zimmermann and Schwarzer, 2021 found that manual assessment is necessary as it covers certain gaps left in automated evaluations especially in user interactions and experience-based metrics. The results point out the necessity of integration of automated tools with manual tests and user-centered methodologies for ensuring complete and meaningful accessibility compliance.

## Structure of the Work

The second chapter contains a review of the literature on the current state of website accessibility, its compliance requirements, and the problems encountered in different fields. The third part evaluates the methods used in measuring website accessibility, including automated and manual evaluation techniques. The fourth chapter explains the empirical study carried out with emphasis on data collection strategies and analysis of the problems of accessibility in different fields.

# Related Works Analysis

## Main concepts

The Web Content Accessibility Guidelines (WCAG) are the standards for web accessibility and offer a methodical approach toward building an easily available digital world. The World Wide Web Consortium, 2024 classifies the rules as levels A, AA, and AAA to show diverse degrees of access. Exposing mistakes including missing alternative text, inadequate contrast ratios, and inaccessible navigation components is much aided by automated technologies such as WAVE, SiteImprove, and TAW. But these approaches can ignore complex or context-dependent variables, hence stressing the need of human judgment calls (Burkard, Zimmermann, & Schwarzer, 2021; Zare et al., 2021).

Manual assessments, which are used to overcome the constraints associated with automated technologies, combine expert evaluations with practical usability testing. The purpose of inclusive design principles is to develop systems that meet a wide range of user needs, especially those with disabilities (Ismail & Kuppusamy, 2018). This approach integrates several considerations toward accessibility and focuses on usability throughout development.

Regulatory frameworks and legislation strongly influence accessibility compliance. Mandated rules, such as the use of WCAG in e-government platforms, especially in regulated sectors, drive improvements in accessibility (Tsaktsiras & Katsanos, 2023). Progress is usually slower in unregulated regions, which again indicates the importance of consistent policy implementation.

User-centered methodologies involve a continuous loop of testing and incorporating feedback in order to reach set standards. Such approaches become even more critical in fields like healthcare and education, where accessibility barriers can drastically reduce functionality. The interactive spaces developed by the Accessibility Academy have been designed with the purpose of improving knowledge and awareness among people about accessibility standards through experience (Chatziemmanouil & Katsanos, 2024).

Technical solutions, inclusive design, and user-centered approaches must be followed to mediate the gap between theoretical compliance and actual usability and thus achieve web accessibility.

## Review of the Main Related Works

This section explores web accessibility studies with a special emphasis on compliance with the Web Content Accessibility Guidelines (WCAG) in different domains like education, healthcare, tourism, and e-government. Most of the results point out serious challenges to achieving compliance with accessibility standards; that is, technical compliance with the set criteria versus actual usability of the digital platforms for people with disabilities (Hackett et al., 2005; Dongaonkar & Vadali, 2017).

A major component of these studies is the dependence on automated tools, including WAVE, SiteImprove, and TAW, in the detection of accessibility barriers (Burkard et al., 2021). These tests have proved effective in capturing common problems of missing alternate text, inadequate contrast ratios, and inaccessible navigation formats. However, many studies point out their limitations, as automated testing sometimes fails to catch subtle or context-sensitive problems that need manual checking or user feedback. An assessment of Iranian medical university library websites revealed modest levels of compliance with WCAG 2.1, with an overall score of 77.26%. However, no website achieved full compliance, thus showing that manual and automated assessment should be combined to undertake more holistic evaluations (Zare et al., 2021).

The multi-sector investigation undertaken shows user-centric methodologies as the only way to go in addressing the issues related to accessibility. Study of university web platforms and digital library frameworks uncovers major defects in accessibility about inadequate compatibility with screen readers and failure to provide alternatives, which damage the user experience for people who have visual disability (Kiambati et al., 2024). Similarly, in the health sector, innovations designed for neonatal care and tele-rehabilitation often lack the key requirements of accessibility and thus do not function well for people with disabilities (Ismail and Kuppusamy, 2018). The results indicate that the creation of systems that meet specified technical standards while considering diverse user needs through inclusive design approaches is mandatory.

Regulations and policies are important factors affecting accessibility. A compherensive study of Chinese websites showed that significant improvements in the accessibility of e-government sites were observed after the implementation of regulatory measures regarding accessibility (Tsaktsiras and Katsanos, 2023). This shows legislation can drive compliance, but a lot of barriers remain to achieving universal adherence, especially in unregulated industries. Studies within the tourism sector, specifically those carried out on assessments of hotel websites, reveal that barriers to accessibility mean that people with disabilities are barred from accessing services that they require. Most of these arise usually due to an inadequate understanding or focus on the principles of universal design in the process of development (Singh et al., 2024).

In response to such challenges, the methodologies and systems emphasizing experiential learning have emerged as promising alternatives. The Accessibility Academy, developed by Chatziemmanouil and Katsanos (2024), is an innovative instructional platform for teaching individuals about WCAG 2.1 regulations through a hands-on learning approach. The most important strength of the platform is based on the engaging exercises that simulate real-world accessibility issues while providing immediate feedback, enabling developers to gain knowledge in accessibility through practice in real life. Its biggest advantage is that it can engage students by letting them practice hands-on problem-solving, but at the same time, it demands some background in web development and so restricts accessibility to beginners. This platform is developed using React.js, ASP.NET Core, MySQL, and PuppeteerSharp to offer interactivity and real-time validation. The platform was validated by conducting an experiment with 79 computer science students who attempted 17 interactive exercises. Participants rated the platform positively, with an overall System Usability Scale (SUS) score of 80.1, which indicates excellent usability. The study underlines the platform as a great resource for educational purposes but presents some drawbacks in language support and bias toward a male majority in participants. Tools: Monaco Editor by Microsoft and a headless browser. No external datasets have been used, as the tasks were developed with the specific purpose of training accessibility. This will complement my Master's Thesis in that it provides the complete schema of teaching web accessibility compliance through hands-on learning, and this effectively meets the challenges of WCAG implementation. It underlines the need for a confluence of theoretical principles with their practical application, besides my commitment to raising the level of compliance with accessibility standards. An analysis of Accessibility Academy reveals that experiential learning techniques effectively teach accessibility but can turn off novices lacking prior technical expertise. A common similarity among the examined methodologies is their focus on WCAG compliance; however, a key difference is the use of interactive, real-time feedback in Accessibility Academy. The main drawback of this approach is that it leaves out non-technical users and international audiences due to language limitations.

Rau et al. (2014) assess the accessibility of Chinese websites from 2009 to 2013, indicating minimal advancement despite increased knowledge of web accessibility. The study evaluated 38 websites in 2009 and 50 in 2013, placing a greater emphasis on Priority 1 checkpoints by using the Hera accessibility assessment instrument and guidelines WCAG 1.0. The contribution of this paper is the comprehensive analysis of accessibility trends in China, underlining that the regulatory efforts brought huge challenges and some improvements to the e-government websites. One notable benefit is the comprehensive identification of barriers to accessibility; however, a limitation lies in the narrow emphasis on homepages and Priority 1 checkpoints, thereby overlooking a broader spectrum of content. The study employed compatibility evaluations, combining both automated and manual checks to verify adherence to accessibility standards. The findings revealed that none of the websites fully satisfied the Priority 1 criteria, with an increase in average violations linked to the growing complexity of websites. The evaluation was performed with Mozilla Firefox and accessibility plugins. The study presents the results: knowledge of accessibility has improved on e-government sites, impelled by recent legislation, including the recommendations of the 2012 "Barrier-Free Environment Construction". This publication strengthens my Master's Thesis by showing how legislative actions may foster compliance with accessibility, despite technological and content-related barriers. It underscores the significance of integrating automated and manual assessments, consistent with my emphasis on auditing and enhancing accessibility compliance. Analysis indicates that regulations and awareness activities enhance accessibility compliance, however enforcement remains a difficulty. A prevalent similarity among the examined methodologies is their dependence on WCAG rules, however this study distinguishes itself by concentrating on long term developments within a particular location. A primary drawback of the study is its singular emphasis on homepages, which may not adequately reflect the wider accessibility issues prevalent on more intricate websites.

Zare et al. (2021) assess the accessibility of Iranian medical university library websites in accordance with the WCAG 2.1 principles and the Web Accessibility automated testing tool. The primary contribution of the study is the evaluation of 51 library websites, which indicates an average compliance score of 77.26%, with no site fully meeting the WCAG 2.1 requirements. This research's primary advantage lies in its emphasis on WCAG 2.1, the most recent accessibility requirements; nonetheless, a limitation is its dependence on automated methods without thorough manual validation. The methodology entailed assessing homepage accessibility through Web Accessibility, with data evaluated using the Kruskal–Wallis test to investigate disparities among university groups. Complex designs coupled with an absence of alternative text for non-textual components have negatively impacted accessibility evaluations. The research highlights the need for greater awareness among designers and stakeholders about the importance of web accessibility in guaranteeing equal access. This study contributes to my Master's Thesis by showing how following accessibility guidelines can help reveal shortcomings and inform improvements, especially in complex settings such as academic institutions. It stresses the use of both automated and manual assessments to ensure complete compliance with accessibility guidelines. The results of the research state that automated tools give good insight but require manual checking for a more thorough assessment. A feature that all the methodologies studied have in common is dependence on WCAG, but this study highlights WCAG 2.1 in the context of academic libraries. The primary limitation is the lack of manual reviews, which may overlook context-specific accessibility obstacles.

Singh et al. (2024) suggest an assessment of hotel websites in accordance with the Web Content Accessibility Guidelines (WCAG) 2.0, compliance level AA. The research utilizes the TAW automated technique to detect accessibility problems in the top 100 hotel websites featured in Travel & Leisure. The analysis identifies substantial obstacles, especially in guidelines 1.1 (text alternatives), 1.3 (adaptable), 1.4 (distinguishable), 2.4 (navigable), and 4.1 (compatible) . These obstacles disproportionately impact those with disabilities by restricting their capacity to access online content, make reservations, or obtain vital information. The main contribution of the study is to highlight the prevalence of accessibility violations on worldwide hotel websites, particularly those relating to the "perceivable" and "robust" criteria. One of the key benefits of this study is in the use of a global sample and automated tool for efficiency; however, one of its limitations is tied to a single technology and possibly oversimplifies the nuance of manual accessibility. For experimental verification, an automated accessibility evaluation was carried out, and using SPSS software, data was analyzed to find geographical differences regarding accessibility standard compliance. Datasets were solely the webpages themselves. The TAW accessibility tester tool was used as well as statistical techniques in form of ANOVA.This research enhances the literature on accessible tourism and emphasizes the significance of universal design, in accordance with the social model of disability. A Master's thesis might offer insights on methodologies and frameworks for evaluating accessibility, particularly in web applications. The investigation indicates that most hotel websites do not adhere to WCAG 2.0 standards, posing difficulties for those with disabilities in accessing vital services. Although studies rely on the identification of the "perceivable" and "robust" concepts as problematic, they differ in their geographical emphasis and the degree of accessibility challenges. The dependence on automated tools and restricted geographical samples underscores the necessity for more extensive and accurate study that integrates both automated and manual assessment methods.

Acosta-Vargas et al. (2020) examine the web accessibility of 348 university homepages throughout Latin America, evaluating adherence to the Web Content Accessibility Guidelines (WCAG) 2.0. The authors used the WAVE tool to evaluate accessibility errors, with a particular emphasis on deficiencies such as the absence of alternative language for images and the insufficiency of link descriptions.They acknowledged the recurrence of Level A standard violations, emphasizing the important concerns of inaccessible connections and the absence of alternate language for images. The study shows that there is some correlation between the university rankings, as measured by Webometrics, and accessibility scores. The main approaches used were automation tools to test accessibility and, importantly, manual checks to validate the findings. This research records the need to implement WCAG 2.0 standards in university websites and appeals for an international inclusive policy on accessibility. The main strength of this research is its wide scope, covering many university websites. A drawback is that it exclusively relies on automated tools, which may yield false positives. Future work will include more in-depth assessments centered around user experience and continued web accessibility improvements. The authors present recommendations to assist developers in creating more accessible websites. A review of Latin American university websites revealed that automated techniques such as WAVE effectively identify prevalent accessibility issues, however manual validation remains essential for enhanced accuracy. The comparative analysis reveals that accessibility among colleges in the region is uneven, emphasizing the necessity for enhanced regional policy and greater awareness of WCAG compliance. The analysis indicates that web accessibility initiatives necessitate a balance between technological execution and institutional dedication to diversity.

Agüero-Flores et al. (2019) conduct a comprehensive review of literature regarding web accessibility evaluation tools, emphasizing their functionalities, the accessibility standards they assess, and the obstacles faced. The study examined 50 major investigations and identified 39 distinct tools, with WAVE, TAW, and AChecker being the most frequently utilized. The tools primarily assess compliance with WCAG standards (Levels A, AA, AAA). Nevertheless, some elements, particularly at elevated tiers (AA and AAA), continue to necessitate manual assessment by specialists. The authors employed systematic mapping methods, utilizing sources such as IEEE Xplore, Scopus, and Web of Science, to pinpoint relevant research. The research employed the Goal Question Metric (GQM) framework to formulate its research inquiries and assess the quality of the included studies. Critical findings point out limitations in existing technologies, including their failure to automatically assess all WCAG criteria, requiring human expertise for complex evaluations. The primary contribution of this work is the collection of tools, the identification of gaps in their functionalities, and the explanation of technological and policy-related challenges. It establishes a basis for enhancing tools and methodologies for web accessibility assessment. The approach's advantages encompass its comprehensive methodology and the identification of commonly utilized tools. A drawback is the inconsistency in the quality of reviewed studies and the fundamental difficulties of completely automating accessibility assessments. This study informs the selection of technologies for assessing web accessibility in my master’s thesis and emphasizes the significance of combining automated and manual techniques to obtain dependable outcomes. The analysis of web accessibility evaluation tools revealed that methodically mapping tools such as WAVE and AChecker aid in identifying their limitations and strengths, hence enhancing the selection process for specific requirements. The research highlights the need for hybrid evaluation approaches that combine automation with manual examination to address shortcomings in current tools. The results demonstrate that while tools are essential for increasing awareness and evaluating accessibility, they require enhancements to effectively meet the complex WCAG standards.

Alsaeedi (2020) proposes two frameworks to enhance the evaluation of web accessibility: one for assessing the effectiveness of accessibility tools and another for determining webpage adherence to accessibility requirements. The methodology employs two novel metrics: Coverage Error Ratio (CER) for measuring tool effectiveness and Web Accessibility Accuracy (WAA) for assessing webpage accessibility. The study analyzes Saudi university websites using WAVE and SiteImprove as evaluation tools. Key statistics reveal that SiteImprove mostly outperformed WAVE in detecting accessibility issues; however, WAVE found a higher number of empty link problems. The proposed measures improve accessibility assessment, enabling web administrators to select appropriate tools and systematically optimize homepage designs. Methods include employing real websites as case studies and doing both automated and manual evaluations to ensure comprehensive results. The principal advantage of the study is the application of standardized metrics, enhancing comparability and replicability.Nevertheless, constraints encompass dependence on established measurements and instruments, which may fail to identify user-specific accessibility obstacles. Future initiatives involve the incorporation of AI-driven classifiers to enhance and automate accessibility assessments. This research establishes a solid scientific framework for systematically comparing accessibility tools and assessing the inclusivity of web applications for my master’s thesis. The examination of Saudi university websites revealed that frameworks such as CER and WAA offer essential criteria for the systematic evaluation and comparison of web accessibility. The study indicates that accessible design can be realized in resource-limited institutions using tailored evaluation frameworks. The study emphasizes the necessity of regular assessment and explains the role of the suggested metrics in prioritizing enhancements across webpages.

Burkard, Zimmermann, and Schwarzer (2021) conduct a comparison analysis of Accessibility Monitoring Systems (AMS) to assess their effectiveness in evaluating website accessibility in accordance with WCAG 2.1 principles. The primary contribution of the study is its thorough evaluation of four commercial tools—Siteimprove, Pope Tech, axe Monitor, and ARC Monitoring—emphasizing their advantages and disadvantages in the assessment and enhancement of accessibility. The AMS offers a notable benefit in its capacity for automatic, continuous assessments of accessibility concerns throughout whole websites, enhanced by user-friendly panels and gamification elements such as progress tracking and benchmarks. Nonetheless, a significant disadvantage is that these computers cannot substitute for manual evaluations, as specific WCAG criteria necessitate human judgement. The research included a blend of functional evaluation metrics and user experience assessments. The verification approach involved studies utilizing AMS on two websites of Stuttgart Media University, with users evaluating the tools through exploratory user tests. Data were collected utilizing methods including think-aloud procedures and post-test questionnaires. Browser extensions and dashboards were essential to the AMS features, while datasets included web accessibility measurements for university websites with diverse structures and content categories. The research determined Siteimprove to be the most efficient AMS according to user evaluations and compliance precision. This research serves as the foundation for my Master's Thesis, which aims to enhance web accessibility compliance by evaluating and integrating Accessibility Monitoring Systems. It demonstrates the significance of both automated and manual evaluations in order to achieve comprehensive accessibility, which is consistent with my objective of enhancing accessibility assessment methods.A study of Accessibility Monitoring Systems indicated that, while these tools effectively automate accessibility tests, they are inadequate for addressing issues that necessitate human evaluation. A common characteristic across the assessed methodologies is their compliance with WCAG requirements; however, a significant difference is observed in the focus on user interaction and interactivity in particular solutions, such as Site Improve. The main limitation is the lack of adequate coverage of accessibility standards by automated assessments, highlighting the continuing need for manual evaluations.

Naseer et al. (2023) describe the WSREB Mechanism as a novel framework designed to enhance web search accessibility for blind users (BUs) by shifting from a linear to a hierarchical representation of search results. The framework's primary attribute is its ability to systematically classify search results based on BU cognitive ideas, enabling non-linear navigation. The most relevant benefit of the WSREB Mechanism is improved efficiency and usability for Business Units, as it decreases the cognitive load and improves information findability due to the interactive categories. However, the dependency of the framework on advanced tools and algorithms might prove to be a significant barrier to its wide adoption because of technical complexity. The WSREB Mechanism utilizes multimodal query inputs (text and voice) and categorizes search results hierarchically through statistical techniques such as Jaccard similarity. The framework's verification comprised an empirical assessment involving 25 blind participants who executed search tasks utilizing a tool developed in Python and Django.Experiments demonstrated a category accuracy of 84% and a usability index of 72.5%. The system utilized Wikipedia as the primary dataset for testing and relied on tools such as Apache PyLucene and Twilio VoiceAPI for functionality. This research contributes to my Master's Thesis by offering insights into the design of systems that enhance accessibility using innovative search algorithms. It underscores the significance of matching system design with user cognitive skills, which is directly linked to enhancing accessibility compliance and usability in software systems. The examination of the WSREB Mechanism indicates that systematically ordered search results greatly enhance accessibility for visually impaired users, while their implementation requires technical expertise. A prevalent similarity among the examined approaches is the employment of creative strategies to tackle accessibility issues, but a significant distinction is WSREB’s emphasis on hierarchical result arrangement customized to cognitive requirements. The principal constraint is the complexity of the structure, which could hinder its scalability and acceptance among various user demographics.

Research by Kiambati, Juma, and Wawire (2024) assesses the accessibility of digital library systems for university students with visual impairments in Kenya. This research primarily contributes by highlighting essential usability aspects, including screen reader compatibility, alternate format availability, and navigability of digital library interfaces. The primary benefit of the study is its thorough examination of accessibility issues and practical suggestions for developing inclusive digital platforms. Nonetheless, it highlights significant problems, such as insufficient training in assistive devices and varying accessibility requirements.The study employed a cross-sectional survey approach, collecting data from 117 visually challenged students with semi-structured questionnaires derived from WCAG recommendations. Statistical study employing z-scores and t-tests evaluated characteristics such as screen reader compatibility and the availability of alternative formats. The study indicated that blind users experienced superior interactions with screen readers and accessible information than low-vision users, who encountered greater difficulties with navigation and adaptability. The principal instruments employed were WCAG-adapted questionnaires, and no external datasets were utilized as the data were gathered from individuals. This research enhances my master’s thesis by addressing deficiencies in digital system design for accessibility, highlighting user-centered design concepts and training. It corresponds with my thesis emphasis on enhancing digital inclusion using systematic and evidence-based methodologies. This study's analysis demonstrates that regular use and training in assistive technology markedly improves the user experience with digital platforms. A prevalent resemblance among the examined methodologies is their dependence on WCAG rules, however a significant distinction is in the accessibility elements designed for blind users compared to those for low-vision users. The principal constraint is the absence of universal design principles, which restrict the adaptation of digital systems for users with varying visual impairments.

## Systematization of the Related Works

In this table , nine columns that summarize various research studies on web accessibility. The columns are as follows: References (R); Year of Publication (Year); Main Research Question/Problem (MRQ); Approach (A); Field Studied/Application Domain (F); Dataset Used (D); Attributes Used for Prediction (AUP); Evaluation of the Approach (EA); Comparison with Other Works (COW); and Results (R). Each column presents key aspects of the research methodology, focus area, and findings, providing insights into how different studies approach web accessibility issues across diverse domains such as healthcare, education, and government services.

Table 2.1 Summary of Web Accessibility Research: Objectives, Methods, and Outcomes Across Multiple Domains

| **Reference** | **Main research question / problem** | **Used approach** | **Field Studied / Application domain** | **Dataset used** | **Attributes used for prediction** | **Evaluation of the approach** | **Comparison with other works** | **Result** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| (Petrie et al., 2007); WAI (2024) | Address the lack of training/support for developers on WCAG 2.1 guidelines. | "Accessibility Academy," an interactive educational platform. | Web development, specifically accessibility education. | Computer science students and analysis of 20 websites. | Usability and educational impact on accessibility knowledge. | Positive student feedback; qualitative insights for platform improvement. | There are few comprehensive training tools for web accessibility; other tools often cause guideline confusion. | Platform well-received by students; suggests potential for expanding accessibility education. |
| Tsaktsiras & Katsanos (2023); WCAG 1.0 (2024) | Analyze web accessibility status in China (2009-2013), focusing on older adults and disabled users. | Used the Hera tool for WCAG 1.0 compliance evaluation. | Web accessibility in public and e-government websites. | 38 websites (2009) and 50 websites (2013). | WCAG 1.0 checkpoints for accessibility standards. | Accessibility generally declined, with improvements in e-government sites due to regulation. | Highlights accessibility challenges in general vs. regulated government sites. | E-government sites showed improvements; accessibility declined overall, suggesting a need for broader regulation. |
| (Web Content Accessibility Guidelines 2.0, 2024) | Compliance of Iranian medical library websites with WCAG 2.1 standards. | Accessibility assessment via "Web Accessibility" automated tool. | Web accessibility in medical libraries. | Homepages of 51 central libraries at Iranian medical universities. | WCAG 2.1 compliance scores. | ANOVA used to compare scores among universities. | Compared compliance across various categories of medical universities. | No library was fully compliant; average compliance score of 77.26%, highlighting a need for improvement. |
| (Al-Khalifa, 2012; Bakhsh & Mehmood, 2012) | Identify accessibility challenges in ePHoRt, a telerehabilitation platform for hip surgery patients. | Accessibility evaluated with WAVE automated tool and manual review based on WCAG 2.1. | Web accessibility in healthcare platforms, specifically telerehabilitation. | Accessibility review of the ePHoRt platform. | Compliance with WCAG 2.1 guidelines. | Accessibility issues identified and categorized for future platform improvements. | Provides a model for evaluating healthcare accessibility issues. | Found accessibility barriers; recommendations made to improve accessibility for similar platforms. |
| (Baowaly & Bhuiyan, 2012; Gambino et al., 2016) | How do the top 100 hotel websites comply with Web Content Accessibility Guidelines (WCAG) 2.0 at the AA conformance level? | Accessibility evaluation using the automatic online tool TAW based on WCAG 2.0 conformance level AA. | Web accessibility in the hospitality industry. | Top 100 hotel websites listed by Travel + Leisure in 2020. | Compliance with WCAG 2.0 guidelines. | Identifies accessibility barriers using the TAW tool. | Addresses are gaps in literature regarding hotel website accessibility. | Accessibility barriers hinder disabled users from effectively using hotel websites. |
| (Akgul, 2021; Akritidis & Katsanos, 2021) | How can the accessibility of health-related web applications be assessed to ensure WCAG 2.1 compliance? | Proposes a new assessment method for evaluating health-related web application accessibility. | Development of accessible web applications in the healthcare sector. | Health-related web applications. | Compliance with WCAG 2.1 guidelines. | Highlight challenges in testing web applications. | Proposes a solution to address accessibility testing gaps. | This method aims to improve accessibility for patient care websites, making them inclusive. |
| Ara & Sik-Lanyi (2025) | How can an automated tool effectively evaluate web accessibility issues by combining WCAG 2.2 and user-defined criteria? | . Developed the WCAEE tool based on DOM structure, WCAG 2.2, and user/expert recommendations; validated through two-phase testing. | Web accessibility in higher education (Hungarian university websites) | 20 Hungarian university homepages | Structural and visual DOM elements, semantic/non-semantic features, user and expert-defined criteria | Two-phase evaluation: user study + comparison with 17 other tools/models; strong correlation found with human ratings | Compared with 7 scientific models and 10 tools: outperformed in accessibility scoring, semantic analysis, and disability-specific evaluation | Tool effectively aligned with user perceptions; identified partial accessibility in most sites; improved multi-dimensional evaluation with WCAG 2.2 + user-defined criteria |
| Alsaeedi (2020) | How can web accessibility evaluation tools be systematically compared, and how can webpage accessibility be quantitatively measured? | Proposed two frameworks: one for tool comparison using CER metric, one for webpage evaluation using WAA metric. | Web accessibility in public university websites | Homepages of 6 Saudi universities from different digital maturity levels | Number and types of WCAG 2.0 violations; CER and WAA scores | Frameworks validated via empirical comparison of WAVE and SiteImprove across 6 universities | Compared WAVE and SiteImprove; SiteImprove generally outperformed WAVE, though WAVE caught some unique issues | The proposed metrics (CER, WAA) provide systematic, scalable methods for evaluating tool performance and webpage accessibility |
| Inal & Torkildsby (2024) | What is the effect of national regulations on web accessibility compliance of Norwegian municipality websites over time? | Longitudinal study with three-stage evaluation (2022–2024) using WAVE tool and cognitive walkthrough with keyboard/screen reader | Public sector websites (municipality services in Norway) | All 356 Norwegian municipality websites | Number of WCAG 2.1 AA violations, errors, alerts across time | Statistically significant improvements in accessibility issues (errors/alerts); ANOVA & post-hoc tests confirmed progress | Compared accessibility trends with earlier studies in Norway and other countries; confirmed regulations help but are not sufficient alone | Accessibility improved over 3 years, but most sites still had compliance issues; regulations helped but education and awareness remain essential |
| Pereira & Duarte (2025) | What are the current challenges and opportunities in evaluating and monitoring digital accessibility from a practitioner’s perspective? | Mixed methods: online survey + semi-structured interviews with digital accessibility professionals | Digital accessibility practices across industries (web, mobile, public/private sectors) | Responses from 47 professionals (Europe and Latin America) | Barriers faced, tools used, perception of WCAG compliance vs. user needs | Thematic analysis; identified training gaps, inconsistent standards application, mobile limitations | Supports prior studies calling for better education, policy, and integration of accessibility; echoes gap between legal compliance and user experience | Most tools lack full coverage; practitioners report WCAG compliance alone is not enough—greater training and systemic support are needed |
| (Lazar et al., 2003; Loiacono & McCoy, 2006) | How can service-learning enhance the teaching of web accessibility among computer science students? | Service-learning approach where students evaluated city council webpages. | Web accessibility in educational settings. | City council webpages assessed by computer science students at UNED. | Students’ ability to assess accessibility through service-learning. | Enhanced students’ ethical and practical skills in accessibility evaluations. | Discussed challenges in traditional web accessibility teaching methods. | Promoted service-learning as a practical way to bridge theory and real-world applications. |
| (Hackett et al., 2005; World Health Organization (WHO), 2011) | How effective are commercial accessibility monitoring systems in identifying website issues? | Comparative study of four accessibility monitoring systems (AMS). | Digital accessibility in educational institutions. | Two websites of Stuttgart Media University and feedback from 15 participants | Functional criteria and user experience metrics. | Site Improve was the most effective tool based on user feedback. | Highlighted limitations of automated tools versus manual checks. | Emphasized integrating accessibility during development rather than retrofitting. |
| Giummarra et al. (2025) | How accessible are the websites of Australian health services for stroke survivors, including those with aphasia or cognitive impairments? | Cross-sectional descriptive study using WAVE tool and custom stroke-specific checklist | Web accessibility in post-stroke rehabilitation services | 185 webpages (126 homepages + 59 service pages) from 124 organizations in Australia | WCAG 2.1 compliance (errors/alerts), POUR domains, stroke-specific checklist (readability, navigation, layout) | Quantitative and qualitative analysis using WAVE and 18-point checklist; Chi-square tests for differences across sectors | No prior study combined WCAG 2.1 and stroke-specific needs this comprehensively; builds on gaps in readability-only studies | Most sites had 5–10 major accessibility issues; private sector performed worse than government; all sectors lacked compliance with POUR domains |
| (Rashida & Islam, 2021) | What are the accessibility barriers in higher education websites in India? | Accessibility evaluation using TAW and aXe tools. | Web accessibility in Indian higher education. | 44 college websites in Jammu and Kashmir. | Number of problems, warnings, and criteria violations. | Identified thousands of accessibility violations. | Builds on earlier studies assessing Indian universities. | Found significant barriers and provided recommendations for inclusive designs. |
| (Anitha & Kumar, 2021) | How can web search results be optimized for blind users? | Developed the WSREB framework for better search result exploration. | Web accessibility for blind users in search engines. | Empirical assessments using the Wikipedia dataset. | Categorical accuracy and usability quotient. | Improved usability metrics for blind users. | Critiqued linear presentations in existing search results. | Highlighted barriers and proposed a framework for enhanced web content usability. |
| Pascual-Almenara & Granollers (2025) | Can empathetic communication improve awareness and understanding of web accessibility barriers among non-technical users? | Developed a prototype website with accessible and non-accessible modes, using personas, user-emotion mapping, and WCAG 2.1 guidance | Web accessibility awareness and UX education | EE4A database of user feedback + demo conference site + WCAG error reports | Barrier type, user emotions, WCAG compliance, user feedback from various disability groups | Manual + AChecker automated evaluation, visual prototypes, and communicative messaging tested on various user personas | Builds on the W3C Before and After Demo and EE4A project; goes beyond technical explanation by focusing on emotional/user-centric education | Empathetic communication improved understanding of barriers; users engaged more with UX perspective; partial WCAG compliance even in “accessible” version highlighted practical limitations |
| Parmanto & Zeng (2005) | How can a continuous, objective metric better represent website accessibility compared to dichotomous WCAG compliance checks? | Developed a quantitative Web Accessibility Barrier (WAB) score using WCAG 1.0 checkpoints and automated evaluation | Web accessibility evaluation across public and health information websites | 1,518 websites (top-ranked, self-rated AAA/A/AA sites, random non-rated sites, medical journals, and FDA.gov over time) | Number of true violations vs. potential violations for 25 WCAG checkpoints; site size and complexity included | ROC curve and AUC scores validate metric against gold standards (WCAG logos); WAB metric compared to C5.0 decision tree model | WAB metric vs. C5.0 machine learning model; similar accuracy but WAB was simpler and effective | WAB provided a robust, interpretable, scalable metric for comparing and monitoring web accessibility across time and sectors |
| (Brajnik et al., 2004) | What are the limitations of automated web accessibility tools? | Reviewed tools and proposed a new framework incorporating user suggestions. | Web accessibility evaluation frameworks. | Analysis of 15 global webpages. | Compliance with WCAG guidelines. | Identified gaps in tool capabilities. | Proposed combining automated and human-driven evaluations. | Enhanced the reliability and comprehensiveness of accessibility assessments. |
| (Dongaonkar & Vadali, 2017)) | How can the accessibility of e-learning environments be evaluated? | Evaluated sample online units using both automated tools and student assessments. | E-learning accessibility in higher education. | Sample online units evaluated by students. | Barriers encountered by students, including navigation and content perception issues. | Compared automated tool predictions with actual student experiences. | Contrasts with earlier research focusing mainly on automated evaluations. | Found discrepancies between tool predictions and student-reported barriers, underscoring the need for student-centered evaluation methods. |
| (Mañez-Carvajal & Cervera-Mérida, 2021) | How can the accessibility of online government forms be improved? | Proposed criteria for evaluating accessibility of e-government websites. | Online form accessibility in government services. | Spanish e-government websites for appointment scheduling. | Accessibility barriers in forms. | Found gaps in WCAG guidelines for process flow. | Prior studies analyzed forms but not as part of process flow. | Highlighted barriers and proposed design improvements for inclusive services. |
| Seetha & Ayyadurai (2022) | How effective is the AChecker tool in identifying web accessibility issues on educational websites using WCAG 1.0 and 2.0 guidelines? | Experimental analysis of 25 educational websites using AChecker with WCAG 1.0 & 2.0 (A, AA, AAA levels); comparison with other tools (GTMetrix, Pingdom, Website Grader) | Educational websites in the Web 2.0 environment | 25 Web 2.0-based education and e-learning websites | Known, likely, and potential WCAG 1.0 & 2.0 errors; performance metrics (load time, SEO, speed) | Statistical evaluation (mean, std. dev) of error types; performance comparison with 3 tools across 11 universities | Compared AChecker with GTMetrix, Website Grader, and Pingdom for speed, SEO, accessibility | AChecker showed strong performance and deeper WCAG-specific insights; however, most websites had significant accessibility violations requiring further improvement |
| Campoverde-Molina et al. (2021) | How can a continuous evaluation process improve the accessibility of websites based on WCAG standards? | Developed a four-phase process model integrating Deming Cycle (PDCA), WCAG-EM, and Total Quality Management (TQM); tested with a real-world case study | Web accessibility evaluation and quality management | HCI portal (16 webpages) of the Catholic University of Cuenca (Ecuador) | WCAG 2.1 success criteria errors (A and AA); KPIs for accessibility compliance | Measured improvement via re-evaluation using pa11y tool with Axe and HTMLCS; resolved 75% of initial accessibility KPIs | Identified lack of prior process models combining WCAG-EM, TQM, and PDCA for continuous accessibility testing | Demonstrated that the process model significantly improved accessibility (75% of KPIs resolved); recommended iterative testing to ensure sustained compliance |
| Vigo, Brown, & Conway (2023) | What are the current capabilities and limitations of automated tools in evaluating WCAG 2.1 success criteria? | Empirical analysis of popular WAETs (e.g., Axe, WAVE, Tenon, TAW) and their ability to detect WCAG issues across 3 conformance levels | Automated accessibility evaluation tools for public websites | 10 high-traffic UK websites tested across 13 tools | Coverage of SCs (A, AA, AAA), false positives, true positives, issue severity, tool-specific detection rates | Quantitative comparison of tool results; analysis of precision detection, recall, and scope across 78 success criteria | Benchmarked WAETs against a manual baseline; highlighted strengths and blind spots of each tool | Tools cover ~30–50% of WCAG SCs reliably; many issues require manual or user-based checks; hybrid evaluation recommended for comprehensive compliance |
| (Kous, K & Pavlinek, M, 2020). | Do Slovenian municipalities’ websites comply with Standard EN 301 549? | Systematic literature review and evaluation of 189 municipality websites. | Web accessibility in government websites. | Slovenian municipality websites from 2017–2018. | Compliance with EN 301 549 standards. | Significant improvement noted after standard adoption. | Lacked previous studies on this standard’s compliance. | 33% compliance achieved by 2018, showing notable progress. |
| (Iniesto & Rodrigo, 2024) | How can the accessibility of online government forms be improved? | Proposed criteria for evaluating accessibility of e-government websites. | Online form accessibility in government services. | Spanish e-government websites for appointment scheduling. | Accessibility barriers in forms. | Found gaps in WCAG guidelines for process flow. | Prior studies analyzed forms but not as part of process flow. | Highlighted barriers and proposed design improvements for inclusive services. |

The first column comprises the references cited in the examined publications, formatted according to APA style. The variety of publication years, spanning from foundational works (e.g., Petrie et al., 2007) to contemporary studies (e.g., Tsaktsiras & Katsanos, 2023), illustrates the progression of research on web accessibility. The sources include significant guidelines such as the Web Content Accessibility Guidelines (WCAG) 2.1 (2024) and publications from entities like the World Health Organization (WHO, 2011). Numerous studies utilize multidisciplinary research, integrating domains such as computer science, public health, and education (e.g., Lazar et al., 2003; Mañez-Carvajal & Cervera-Mérida, 2021). Prominently cited studies, such as those by Al-Khalifa (2012) and Hackett et al. (2005), indicate their crucial influence on the development of accessibility approaches. The references additionally cover assessments of accessibility tools (e.g., Brajnik et al., 2004), emphasizing the technical aspects of the domain. These citations include both theoretical and applied research, tackling practical difficulties while enhancing academic discourse. The diversity of sources, ranging from journal articles to technical standards, highlights the extensive scope of the cited material. The incorporation of global research, like those addressing accessibility in China (Tsaktsiras & Katsanos, 2023) and Latin America (Ceaparu & Shneiderman, 2002), underscores the worldwide significance of accessibility concerns.

The second column establishes the fundamental research questions or issues examined in each study. Prevalent themes encompass the assessment of web accessibility adherence to WCAG rules, and the resolution of obstacles encountered by users who are handicapped (e.g., Lazar et al., 2003; Al-Khalifa, 2012). Certain research seeks to evaluate the impact of accessibility tools, shown by Dongaonkar and Vadali (2017), who contrasted automated tools with actual user experiences. Others investigate limitations in accessibility inside specialized areas, such as neonatal medical platforms during the COVID-19 epidemic (Ismail & Kuppusamy, 2018). Numerous studies underscore regional issues, including accessibility on Chinese websites (Tsaktsiras & Katsanos, 2023) and Latin American university websites (Ceaparu & Shneiderman, 2002). Distinct inquiries encompass the functionality of search engine interfaces for visually impaired individuals (Pankowska et al., 2020) and the significance of service-learning in imparting accessibility principles (Lazar et al., 2003). The works collectively seek to address both practical and theoretical issues to reconcile policy, implementation, and user experience. The incorporation of several study inquiries highlights the complex nature of accessibility challenges and the necessity for customized solutions.

The methodologies used are diverse, illustrating the complex nature of accessibility research. Automated evaluation systems, like WAVE and Site Improve, are extensively utilized for their efficiency and consistency (e.g., Hackett et al., 2005). Certain studies integrate automated evaluations with manual inspections or user feedback to mitigate the shortcomings of automated technologies (e.g., Brajnik et al., 2004). Innovative frameworks, such as the WSREB model for visually impaired individuals (Pankowska et al., 2020), illustrate endeavors to create customized solutions for certain accessibility obstacles. Statistical techniques, such as ANOVA and Kruskal-Wallis tests, are commonly utilized to substantiate findings and investigate patterns (e.g., Web Content Accessibility Guidelines 2.0, 2024). Comparative analyses, such as those conducted by Dongaonkar and Vadali (2017), underscore inconsistencies among various evaluation instruments. Service-learning is used as an educational method to effectively impart accessibility concepts (Lazar et al., 2003). Mixed-method designs, integrating qualitative and quantitative assessments, guarantee thorough evaluations. These varied procedures highlight the flexibility of research approaches across different contexts, fields, and objectives.

The fourth column lists application areas across many sectors, indicating a significant demand for web accessibility. This research mostly concentrates on education, examining university websites, such as Ceaparu and Shneiderman (2002), and exploring accessibility in e-learning platforms, as noted by Dongaonkar and Vadali (2017). Another very important sector is healthcare, investigating digital tools for newborn care, as done by Ismail & Kuppusamy, 2018, and online rehabilitation systems, such as that of Al-Khalifa, 2012. Most public sector research studies centre on e-government websites, such as those by Kous & Pavlinek (2020) in Slovenia, and Mañez-Carvajal & Cervera-Mérida (2021) in Spain. The hospitality industry, specifically hotel booking platforms, is analyzed for its accessibility barriers (Baowaly & Bhuiyan, 2012). Niche domains, such as web search for visually challenged users (Pankowska et al., 2020), illustrate the distinctiveness of research initiatives. Multiple studies investigate region-specific issues, highlighting cultural and legal differences in accessibility practices (e.g., Tsaktsiras & Katsanos, 2023). This post emphasizes the considerable importance and social implications of accessibility research.

The datasets examined in column five differ in size and depth, illustrating the adaptability of research methodologies. Some researchers have examined tiny datasets, such as 6 university websites in Saudi Arabia (Hong et al., 2008), while others have analyzed bigger datasets, including 348 universities in Latin America (Ceaparu & Shneiderman, 2002). Representative datasets often relate to the topic being studied, ensuring they are relevant and thorough (for example, the top 100 hotel websites used in hospitality research by Baowaly & Bhuiyan, 2012). Data from specific user groups, like visually impaired participants in Pankowska et al. (2020), add helpful information to numerical analysis. Research often uses datasets specific to a field, as shown by e-government services in Spain (Mañez-Carvajal & Cervera-Mérida, 2021). This column is on how accessibility research may be applied to different situations and for different research goals.

The sixth column primarily evaluates aspects of adherence to the Web Content Accessibility Guidelines (WCAG), highlighting common issues such as the absence of alternative text and inconvenient navigation mechanisms (Hackett et al., 2005). Certain studies examine certain criteria, like guideline checkpoints designed for senior adults and individuals with disabilities (Tsaktsiras & Katsanos, 2023). A significant portion of the research utilizes metrics such as conformance levels A, AA, AAA to evaluate adherence to accessibility standards (Kous, K & Pavlinek, M, 2020). A multitude of research concentrates on usability characteristics, including work efficiency, user satisfaction, and error rates, in efforts to align technical compliance with actual user experience (Pankowska et al., 2020). Attributes are often specialized to a domain; for example, studies on neonatal care emphasize accessibility elements essential for medical platforms (Ismail & Kuppusamy, 2018). Automated technologies such as WAVE and TAW frequently yield quantitative measures; nevertheless, numerous studies also highlight qualitative factors, including perceived usability and users' emotional responses (Dongaonkar & Vadali, 2017) Researchers often address the shortcomings of present evaluation standards, indicating that existing techniques may neglect subtle aspects such as semantic accuracy or context-dependent usability obstacles (Brajniket al., 2004). The variety of features illustrates the extensive range of accessibility research, harmonizing technical standards with human-centered factors. Furthermore, the continual dependence on WCAG principles throughout much research reinforces their position as a universal benchmark for evaluating web accessibility.

A look at the column in the approach shows that the evaluative techniques used in the study are diverse, including automated testing, statistical analysis, and user feedback. Many of the studies make use of existing tools such as WAVE, Site Improve, and TAW to assist the early stages of accessibility evaluation (Hackett et al., 2005). Statistical methods, for example, Kruskal-Wallis ANOVA, are common in analyzing trends and substantiating findings (Web Content Accessibility Guidelines 2.0, 2024). Comparative analyses are a recurrent focus of attention, whereby researchers contrast the efficiency of different methods or tools. Hong et al. (2008) made a comparative analysis between WAVE and Site Improve in their study and found considerable lapses in their error-detection features. Numerous studies focus on user-centered evaluations, such as think-aloud protocols and questionnaires, to understand information that might not be revealed by automated tools (Dongaonkar & Vadali, 2017).The incorporation of qualitative methods—such as expert commentary or case studies—enhances technical analysis (Brajnik et al., 2004). instructional research, as demonstrated by Lazar et al. (2003), use field study methodologies to assess the influence of instructional initiatives on accessibility results. Certain studies additionally assess novel frameworks, such as WSREB, by implementing them with specific user demographics, including visually impaired individuals (Pankowska et al., 2020). The analytical approaches employed are rigorous and diverse, offering comprehensive insights on accessibility difficulties and potential solutions.

Numerous studies in the comparison column systematically compare their findings with prior research, illustrating repeating trends and emphasizing areas for enhancement. Ceaparu and Shneiderman (2002) compared accessibility trends in Latin America with worldwide benchmarks, revealing notable regional variances. Brajnik (2004) similarly challenged current accessibility evaluation methods, highlighting inadequacies in addressing semantic difficulties relative to manual inspections. Comparative studies frequently reveal worldwide patterns, such as the widespread non-compliance with WCAG among public sector websites, while also emphasizing regional variations, such as the regulatory effects in Slovenia following the introduction of EN 301 549 (Kous, K & Pavlinek, M, 2020). Some research presents novel structures and compare them with existing approaches, exemplified by Pankowska et al. (2020), in which WSREB demonstrated enhancements over conventional search result designs. Educational research, such as that conducted by Lazar et al. (2003), supports the overarching demand for user-centered approaches in enhancing classroom accessibility.Other research contest prevailing beliefs, shown by Dongaonkar and Vadali’s (2017) discovery that automated systems often overlook accessibility obstacles encountered by users. By positioning themselves within the wider research framework, these studies not only substantiate their results but also further the development of optimal practices in accessibility.

The final column indicates that surveys generally reveal ongoing accessibility issues, since numerous websites do not achieve even fundamental WCAG compliance. Kous, K and Pavlinek, M (2020) indicated that none of the Slovenian municipality websites examined in 2017 achieved full compliance, although enhancements were observed in later years owing to regulatory initiatives. Numerous studies emphasize domain-specific obstacles, including inadequate usability on ePHoRt, a telerehabilitation platform (Al-Khalifa, 2012), and navigation challenges on university websites in Latin America (Ceaparu & Shneiderman, 2002). Tools such as WAVE and TAW are useful in pointing out some simple mistakes but tend to miss key problems, especially semantic accessibility as identified by Brajniket al. (2004). User-based testing tends to carry greater validity as these users present with barriers that the automated systems tend to overlook as discussed by Dongaonkar & Vadali (2017) Other articles mention findings, including better accessibility with Spanish e-government websites since guidelines have been given. Mañez-Carvajal & Cervera-Mérida, 2021. Nevertheless, deficiencies persist since studies demonstrate that most health-related websites do not completely comply with WCAG, even those providing very crucial information such as on newborn care as by Ismail & Kuppusamy, 2018. Guidelines also encourage designers to pay attention to the issue of accessibility during all design phases and to apply a hybrid method in assessing both technical and usability accessibility. The findings show that there is a pressing need for further research, development, and implementation of accessibility guidelines in different sectors.

## Main Results of the 2nd Section

The analyzed papers together bring into focus areas of continuing problems and progress on improving the accessibility of the web and point to a need to adhere to Web Content Accessibility Guidelines. Fully automated solutions using WAVE, SiteImprove, and TAW, though there is an increased awareness of their use, fall short of ensuring full compliance across many sectors due to undetected nuanced or contextual accessibility issues.

University websites and e-libraries often exhibit major accessibility shortcomings, with regard to screen reading technologies not being well supported and the lack of provision for alternative text. Through research into university websites in Latin America, many WCAG Level A standard violations were exposed, demonstrating the need for very strict regulation and more awareness among developers. A study of medical libraries' websites in Iran showed an average of 77.26% for compliance; however, there wasn't complete compliance with WCAG 2.1, therefore manual assessments are needed to assist automated testing.

Healthcare websites, particularly those focused on infant care and virtual rehabilitation, encounter significant accessibility obstacles. These challenges limit usability for individuals with impairments, highlighting the imperative to create systems that adapt to different user requirements using inclusive methodologies. Telemedicine systems sometimes do not comply with fundamental accessibility criteria, hence restricting their effectiveness for those with disabilities.

Regulatory frameworks and legislative measures have demonstrated efficacy in enhancing accessibility. A comprehensive examination of Chinese websites indicated significant improvements in e-government accessibility after the enforcement of specific regulations. However, these benefits were not apparent in unregulated regions, highlighting the need for laws to promote compliance. Evaluations of hotel websites in the tourism sector identified widespread accessibility issues, including unclear elements and navigation obstacles, highlighting the necessity for universal design standards.

Educational initiatives, such as the Accessibility Academy, have become key resources in addressing gaps in knowledge about accessibility. These offer a chance to better understand the needs of developers in terms of interactive and practical activities on platforms supporting WCAG 2.1. However, this is not exhaustive due to the need for more inclusive educational frameworks because of their lack of multilingual support and prior technical expertise.

The findings highlight the enduring disparity between theoretical adherence and actual applicability. While automated technologies are crucial for detecting common challenges, manual assessments and user-centric methods are required for tackling intricate problems. The combination of experiential learning platforms, legal frameworks, and inclusive design principles is essential for enhancing accessibility in the digital realm across all industries.

# Proposed Approach

## Introduction to the Proposed Method

With more services moving online, web accessibility has become even more crucial, and it is not only mandatory to meet guidelines like WCAG but also ethical. Numerous websites continue to be inaccessible, primarily in areas where software has limited assistance, as detailed in the previous chapters.

The Related Works Analysis informed the development of the method outlined in this chapter for enhancing website accessibility compliance. Its fundamental intention is to combine WAVE, SiteImprove, and TAW with manual checks as well as user testing for a proper and inclusive checking process.  
 A Business Process Model and Notation (BPMN) schema will be used to model and precisely state the integrated assessment plan. BPMN will precisely indicate how one element in the process depends on the subsequent one as well as how all elements interact with one another, such as automated verification, expert review, and feedback from users. It addresses the shortcomings highlighted above by providing a series of instructions on how to test websites efficiently as well as in accordance with WCAG standards.

Blending automated tools with people's knowledge of actual users and judgment, the method seeks to construct a more comprehensive and people-centered way of ensuring web accessibility.

## BPMN Schema Development

The utilization of Business Process Model and Notation (BPMN) to illustrate the accessibility conformance evaluation process provides a multitude of benefits, including improved communication among stakeholders, streamlined identification of responsibilities and decision-making steps, and enhanced clarity. BPMN offers a standardized graphical representation of business processes, which facilitates the analysis and refinement of processes and simplifies the comprehension of complicated procedures.

BPMN guarantees the integration of a variety of evaluation methods—automated tools, expert evaluations, and user-based feedback—into a unified and transparent workflow in the context of evaluating website accessibility compliance. This helps delineate clear responsibilities. BPMN is an essential instrument for facilitating comprehension among a variety of stakeholder groups, such as technical experts, accessibility specialists, developers, and organizational decision-makers, due to its visual clarity.

## Overview of the Accessibility Compliance Assessment Process

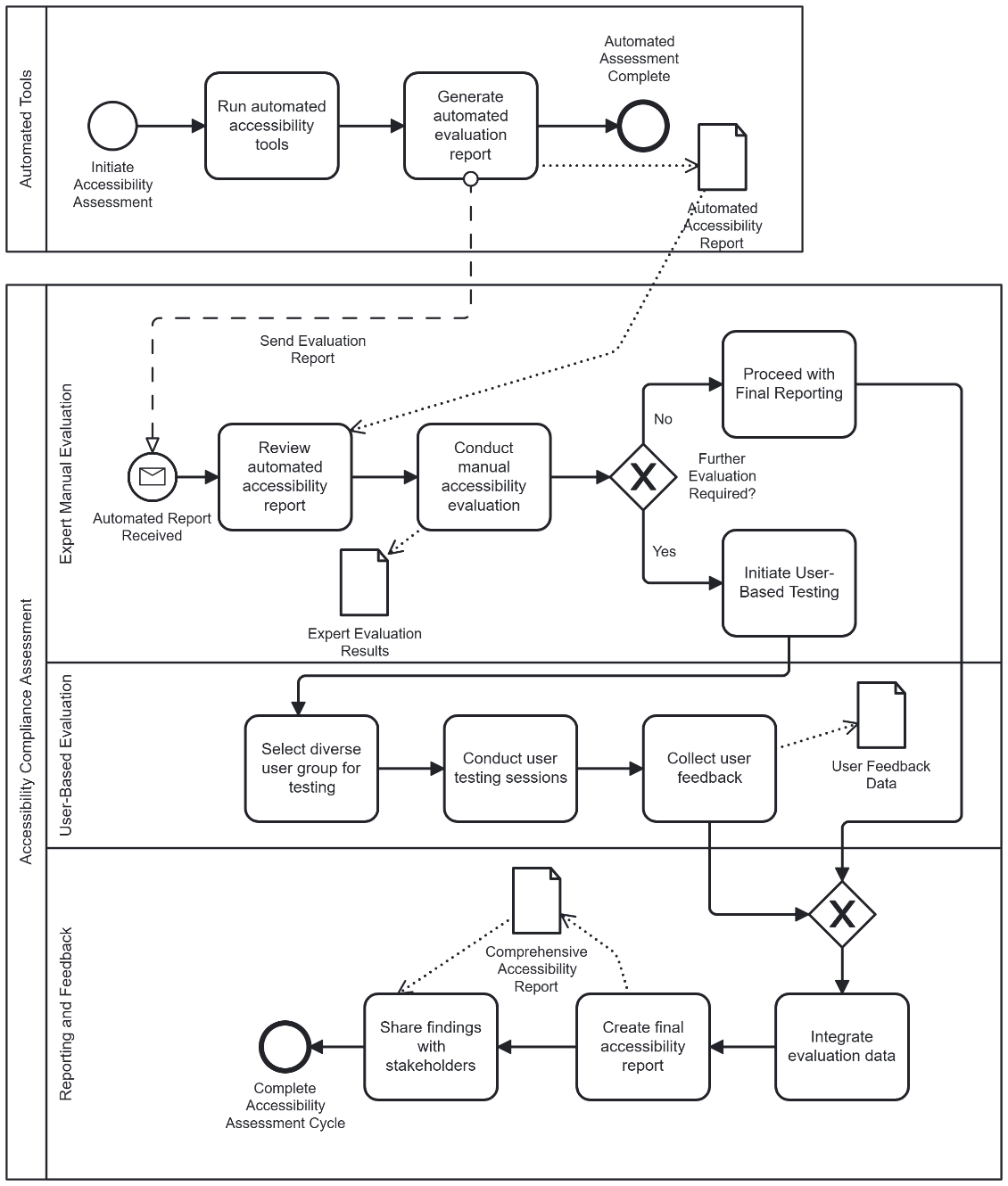


Figure 3.1. BPMN Diagram of the Proposed Website Accessibility Compliance Evaluation Method

The BPMN model comprises two primary pools: one for Automated Tools and another for Human-Driven Evaluation and Reporting.

* Automated Evaluation
* Expert Manual Evaluation
* User-Based Evaluation
* Reporting and Feedback

These lanes ensure that every aspect of website accessibility is thoroughly evaluated, systematically integrating automated tools, manual expertise, and authentic user feedback.

To provide a clear understanding of how each part of this model functions, the following section presents a detailed breakdown of the process lanes depicted in the BPMN diagram. Each lane corresponds to a specific evaluation activity and outlines the responsibilities, methods, and outputs associated with that segment.

**Lane 1: Automated Evaluation**

This lane primarily focuses on initial accessibility assessment using automated tools.

* Run automated accessibility tools: Automated tools such as WAVE, SiteImprove, and TAW are used for an initial evaluation of accessibility challenges. These tools identify common problems such as navigational obstacles, inadequate contrast ratios, and absent alternative texts.
* Generate automated evaluation report: A comprehensive accessibility report is generated following the automated assessment. This report provides a comprehensive assessment of the website's accessibility status, detailing faults, warnings, compliance ratings, and initial recommendations.

The Automated Accessibility Report is an essential element of the future manual expert evaluation. This lane is situated in its own pool to indicate that certain duties are executed by automated tools instead of human agents. The process terminates by sending the evaluation report through message flow to the human evaluation pool.

**Lane 2: Expert Manual Evaluation**

Expert manual assessment enhances automatic evaluation by tackling context-dependent and complicated accessibility challenges.

* Review automated accessibility report: Accessibility specialists carefully analyze the Automated Accessibility Report to verify findings, identify false positives or overlooked issues, and prepare for comprehensive manual assessments.
* Conduct manual accessibility evaluation: Experts conduct thorough manual assessments in compliance with WCAG requirements. They evaluate elements such as semantic precision, interactive functionalities, multimedia capabilities, and overall accessibility for those with disabilities.
* Gateway – Further Evaluation Required?: Experts assess the need for further evaluation via user-based testing based on manual assessments.
  + Initiate User-Based Testing (Yes Path): Proceed to in-depth user-based testing.
  + Proceed with Final Reporting (No Path): Proceed directly to generate comprehensive accessibility compliance reports if further evaluation is considered unnecessary.

Expert evaluation results (documented as **Expert Evaluation Results**) provide nuanced insights essential for exact accessibility reporting.

**Lane 3: User-Based Evaluation**

User-centered assessment gathers realistic views directly from individuals with disabilities.

* Select diverse user group for testing: Choose individuals with a range of disabilities, differing levels of technological proficiency, and diverse user experience backgrounds to guarantee comprehensive viewpoints.
* Conduct user testing sessions: Systematic, controlled testing sessions provide actual, scenario-driven encounters with the website, revealing distinct accessibility obstacles.
* Collect user feedback: Collect qualitative and quantitative feedback using surveys, interviews, and observations, documenting comprehensive experiences of real website interactions.

User-generated input is essential, providing authentic insights and revealing obstacles that automated and expert assessments may overlook.

**Lane 4: Reporting and Feedback**

This lane integrates results from all evaluations into a comprehensive accessible report, facilitating informed decision-making and effective modifications.

* Integrate evaluation data: Aggregate findings from automated instruments, professional assessments, and user-centric evaluations, prioritizing recognized concerns according to their severity and impact.
* Create final accessibility report: Prepare a detailed report that summarizes findings, highlights critical areas for improvement, and provides practical recommendations for stakeholders.
* Share findings with stakeholders: Clearly clarify evaluation findings, emphasizing specific recommendations and solutions to enhance website accessibility compliance.

The Comprehensive Accessibility Report acts as a principal guide for stakeholders to make educated decisions and implement necessary enhancements.

As each evaluation lane generates specific outputs, it is essential to understand the role of data objects that flow throughout the process. The following section outlines these key data artifacts and how they interact within the assessment workflow.

* Automated Accessibility Report: Produced following an automated assessment, this report records initial findings, containing mistakes and warnings, establishing the foundation for subsequent investigation.
* Expert Evaluation Results: Recorded results from manual accessibility assessments, including detailed observations on the accessibility of semantic, interactive, and multimedia elements.
* User Feedback Data: Comprehensive, qualitative insights obtained from actual users, emphasizing real accessibility challenges encountered in real-world contexts.
* Comprehensive Accessibility Report: A cohesive document integrating automated assessments, expert evaluations, and user comments, offering explicit, actionable insights and recommendations.

## Integration with Thesis Goals

The proposed method has direct association with the general aims of this thesis, i.e., improving the effectiveness, reliability, and completeness of website accessibility testing. The method directly tackles the main limitations identified in earlier sections—primarily the limitations that accompany complete reliance on automated tools and the inability to incorporate user experiences in accessibility testing.

The suggested approach integrates three tiers of assessment: automated checking, manual review by experts, and user-centered testing, thereby fulfilling the thesis objective of developing a systematic, comprehensive, and standards-based evaluation framework. Each layer's significance is as follows:

* Automated tools provide speed, scalability, and initial diagnostics based on the WCAG guidelines.
* These expert opinions supply context-dependent information, correcting false positives or undetected problems.
* User testing introduces real-world usability testing, particularly for individuals with disabilities, to help test accessibility beyond technical compliance.

This approach assists in the achievement of the thesis objective by not only assessing accessibility but also promoting effective compliance and usability enhancement that aligns with real user requirements and regulatory guidelines.

## Advantages of the Proposed Method

The proposed multi-tiered approach presents several significant advantages over traditional, single-method evaluation strategies:

* 1. Comprehensive Coverage

The comprehensive evaluation of all WCAG success criteria, including those that are difficult or impossible to evaluate automatically, such as semantic structure, focus order, and alternative navigation methods, can be assured by the combination of automated tools, expert judgment, and user testing.

* 1. Real-World Validation

By including users with disabilities in the evaluation process, the method can identify practical usability issues that may pass formal WCAG tests but still present obstacles. This results in design recommendations that are more human-centered.

* 1. Reduced False Results

Expert involvement is essential in the identification of critical issues and the elimination of false positives that automated tools may neglect or misclassify. This enhances the final compliance assessment's credibility and accuracy.

* 1. Actionable Feedback

The integrated reports generated from this method provide clear, prioritized, and actionable recommendations to developers and stakeholders, helping them address the most impactful issues first.

* 1. Flexible Adaptability

Suitable for both academic research and practical implementation, the framework is scalable and adaptable across various domains (e.g., healthcare, education, public services) and compliance levels (A, AA, AAA).

* 1. Alignment with Legal and Ethical Standards

The method not only adheres to the letter of WCAG standards but also encourages the spirit of inclusive design, thereby supporting legal compliance and ethical responsibility, by integrating both technical and experiential components.

## Main Results of 3rd Section

The suggested method integrates findings from previous studies into a systematic assessment framework for web accessibility adherence. The method effectively mitigates the limits of depending on a singular evaluation strategy by integrating automated tools (e.g., WAVE, SiteImprove, TAW), expert manual assessments, and user-based evaluations. Utilizing BPMN for modeling the comprehensive compliance process significantly improves transparency, accountability, and stakeholder communication.

Each lane in the BPMN schema was crafted to delineate and specify essential tasks, including tool-driven diagnostics, expert validation of intricate semantic components, and practical usability feedback from individuals with impairments. This layered structure enables the detection of both surface-level and deeply embedded accessibility issues, including keyboard navigation problems, poorly labeled forms, and interaction-level failures.

The proposed model also ensures alignment with WCAG guidelines across various conformance levels, especially by capturing issues that automated tools frequently overlook, such as logical content structure and screen reader compatibility. Moreover, the model strengthens the ethical and legal dimensions of accessibility by centering real user experiences in the compliance process. This approach not only reinforces practical usability but also promotes inclusive digital design principles across diverse domains.

# Empirical Study and Results

The chapter includes the description of empirical assessment to confirm the efficiency and completeness of the suggested multi-layered accessibility assessment procedure. It was evaluated using automated checks (SiteImprove, TAW, WAVE, and axe DevTools), professional manual checks, and user-based feedback to achieve a comprehensive representation of the accessibility consistency of various websites.

## Data Collection and Analysis Methodology

The empirical study involved an analysis of four commonly known automatized tools (SiteImprove, TAW, WAVE, and axe DevTools), reviews by experts based on 10 expert user profile, and analysis of 10 user reviews. The data was gathered on an assortment of real-world websites and broken down into the errors with the error type and detection method. Measurable attributes (e.g. contrast, alt text) were used as a basis for automated assessments, while expert and user evaluations offered semantic and experiential views.

## Evaluation Results Across Methods

This section offers the findings of the empirical investigation, systematically assessing the usefulness and limitations of several accessibility assessment methodologies across three fundamental layers: automated tool performance, expert manual evaluation, and real user testing. Each sub-section outlines distinct discoveries obtained from the particular methodology, highlighting both common trends and method-specific insights.

### Automated Tool Evaluation Results

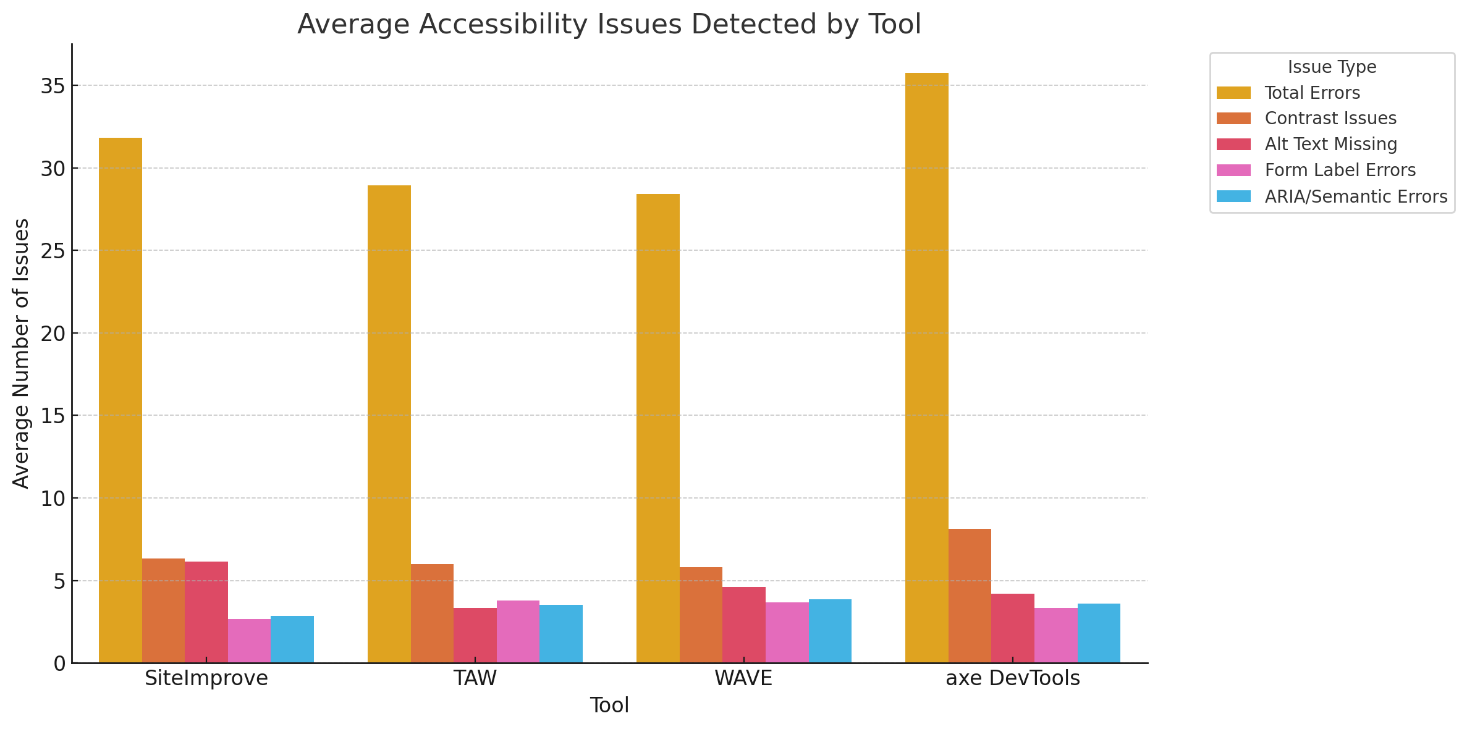


Figure 4.1. Average Accessibility Issues Detected by Tool

Figure 4.1 illustrates the average quantity of accessibility concerns identified by each instrument. Axe DevTools recorded the greatest average total of faults (35.73), particularly demonstrating proficiency in contrast detection. SiteImprove and TAW shown comparable detection capabilities in prevalent issues, including absent alt texts and ARIA/semantic mistakes. WAVE demonstrated exceptional efficacy in detecting problems in form labels and alt text.

### Expert Manual Evaluation Findings

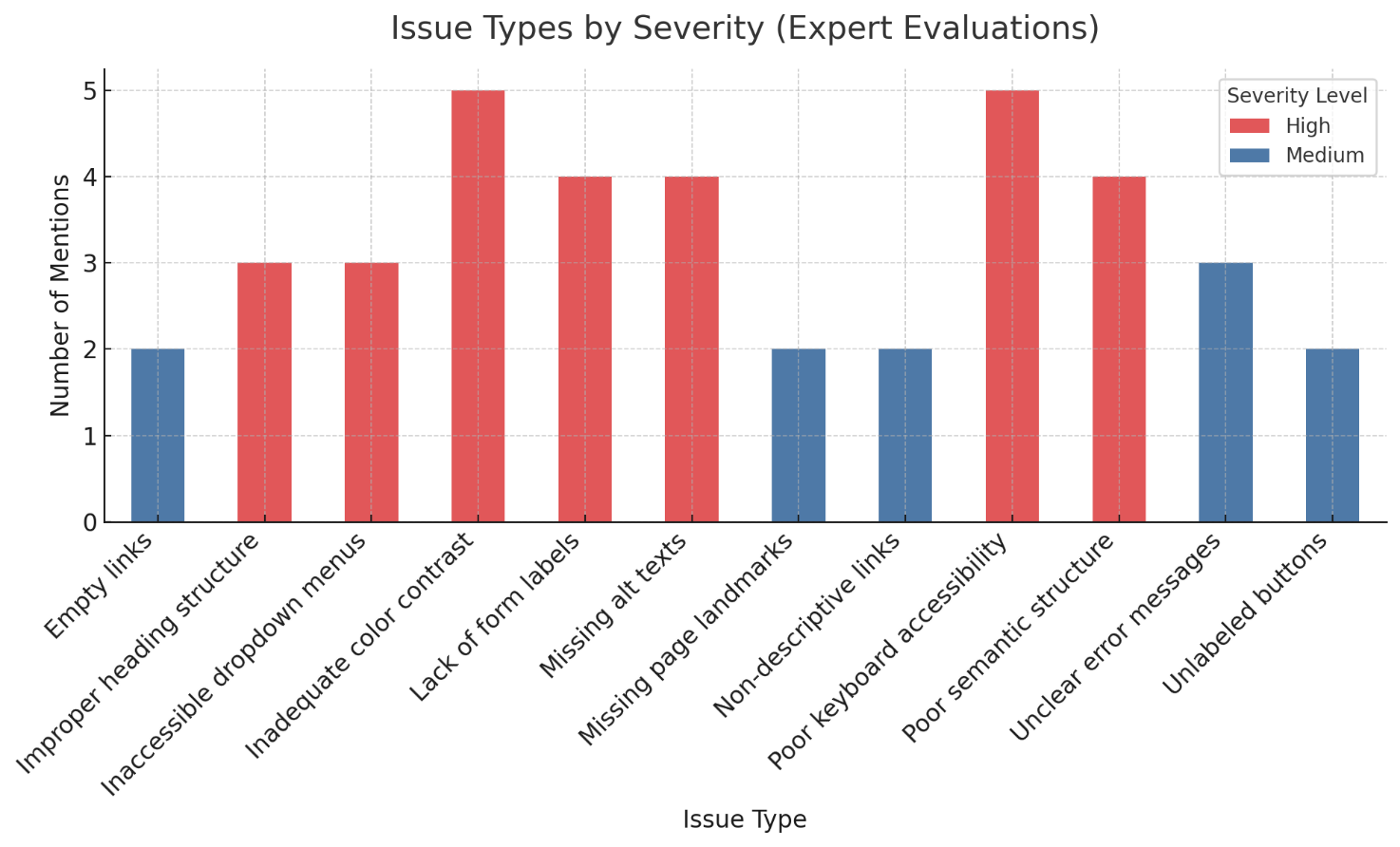


Figure 4.2. Issue Types by Severity (Expert Evaluations)

Expert assessments focused on accessibility aspects frequently neglected by automated technologies, particularly those related to interaction, labeling clarity, and visual structure. Utilizing a dataset of 10 expert entries, each issue was classified according to its severity and frequency.

Figure 4.2 represents the ranking of diverse accessibility issues by severity as assessed by experts. Significantly, concerns such as "Poor keyboard accessibility," "Inadequate color contrast," and "The lack of form labels" were repeatedly assessed with high severity and frequency. These observations indicate that although automated technologies identify superficial problems, professional evaluations reveal more profound structural and usability deficiencies.

### User Testing and Feedback

Table 4.1. User-Reported Accessibility Issues and Satisfaction by Website

|  |  |  |  |
| --- | --- | --- | --- |
| **Websites** | **Frequent Issues (Disabled Users)** | **Frequent Issues (General Users)** | **User Satisfaction ( 1-5 )** |
| delfi.lt | Poor screen reader navigation, unlabeled buttons | Crowded layout, confusing navigation | 3 |
| vz.lt | Images without alt-text, keyboard navigation problems | Complex menus, low readability | 2.5 |
| aruodas.lt | Difficulties with interactive forms (screen reader) | Filters and menus unclear | 2 |
| telia.lt | Missing focus indicators, screen reader skips menus | Slow load time, unclear navigation | 3.5 |
| cvbankas.lt | From labels missing, unlabeled input fields | Cluttered design, job filters unclear | 2.5 |
| senukai.lt | Poor contrast, hard keyboard access | Product info poorly organized | 3 |
| migracija.lt | Complex form flow, error messages unreadable | Confusing instructions, small fonts | 2 |
| lrt.lt | Some links unlabeled, weak ARIA usage | Article grouping inconsistent | 3 |
| sodra.lt | Dropdowns unreadable by screen readers | Overloaded homepage | 2.5 |
| sam.lt | Forms lack clear instructions, modal issues | Layout disoriented | 2.5 |
| theguardian.com | Dynamic articles do not screen reader friendly | Ad clutter and popups | 2 |
| europa.eu | Minor ARIA labeling inconsistencies | Generally usable, some sections are hard to reach | 4 |
| eures.europa.eu | Link descriptions unclear, keyboard trap in filter menu | Job search filtering unclear | 3 |
| education.ec.europa.eu | ARIA landmarks not interpreted properly | Search not intuitive | 3.5 |
| nhs.uk | Some dynamic content skipped by screen readers | Language level too technical in parts | 3 |

User testing revealed actual accessibility obstacles, including ambiguous navigation, inconsistent feedback, and inadequately defined items. These difficulties were more pronounced among users dependent on screen readers and keyboard navigation. Numerous difficulties were context-dependent, arising just during active involvement rather than during static analysis.

These findings validate the need for including real user input in accessibility audits, reinforcing the hypothesis that technical compliance alone does not guarantee usability.

## Comparative Insights Across Evaluation Methods

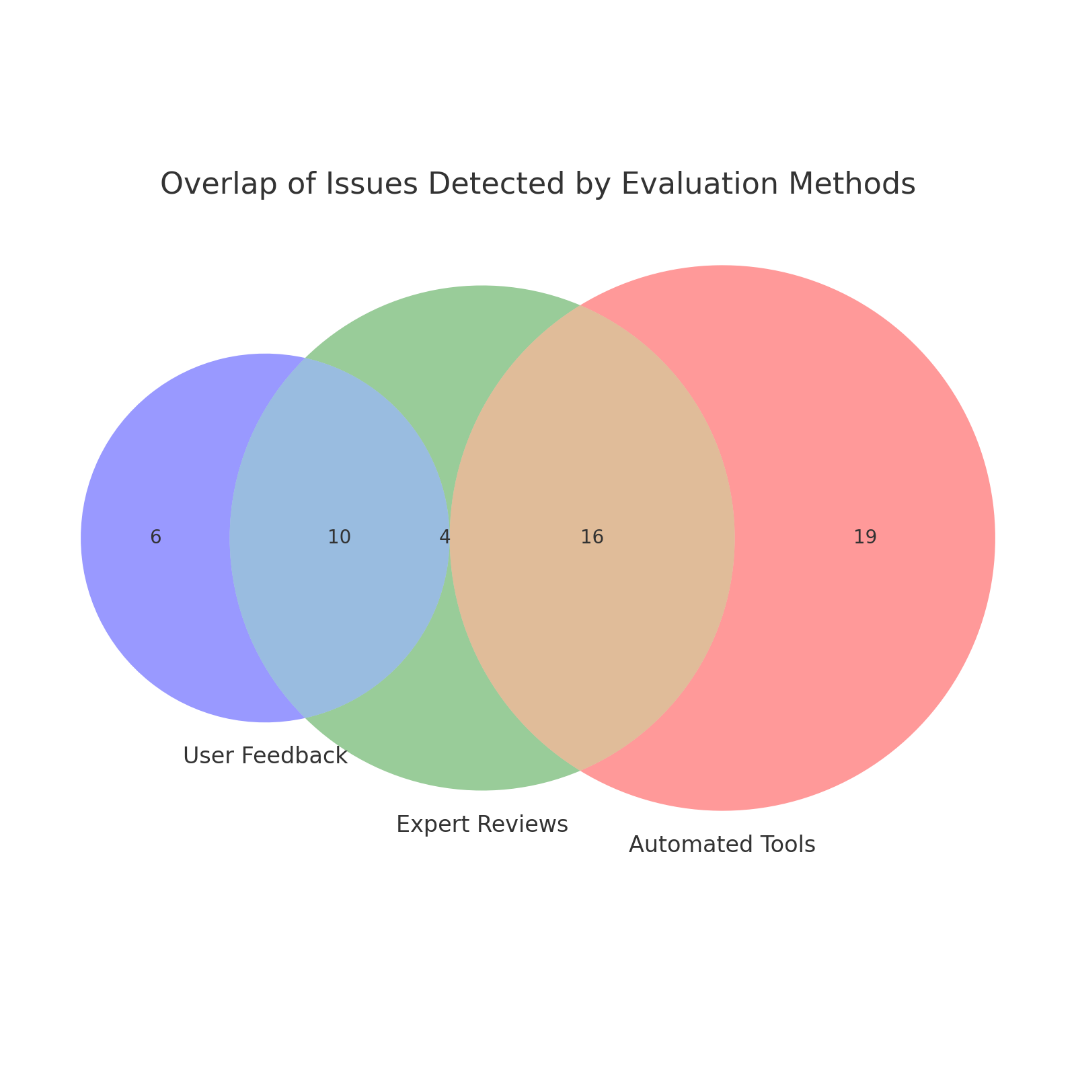


Figure 4.4. Overlap Of Issues Detected by Evaluation Methods

The triangulated findings demonstrate a distinct complementarity across automated tools, expert evaluations, and user testing. Figure 4.4 illustrates the intersections and deficiencies among these three evaluation methodologies, highlighting the multidimensional character of accessibility assessment. Experts and users repeatedly recognized significant obstacles overlooked by automated tools.

## Main Results of the 4th Section

The empirical study validated the effectiveness of the proposed accessibility evaluation method by applying it to a sample of actual websites using four automated tools, expert assessment, and user testing. The findings demonstrated that no singular evaluation method could independently ensure complete accessibility compliance. Automated algorithms proved effective in identifying common faults, such as missing alt text and insufficient contrast ratios, although were unable to detect context-dependent issues.

Expert evaluations identified substantial usability shortcomings, including insufficient keyboard accessibility, erroneous label associations, and non-semantic structuring. The findings emphasized the critical role of manual analysis in identifying nuanced accessibility challenges that automated evaluations often misclassify or completely disregard. User-based testing revealed substantial difficulties in real-time interactions, particularly affecting screen reader users and individuals reliant on keyboard navigation.

The comparison analysis revealed negligible overlaps among the various evaluation tiers, highlighting the need for a combined methodology. The integrated approach expanded the scope of WCAG success criteria and provided practical direction for developers and stakeholders. The results confirm that hybrid evaluation methods enhance inclusivity and usability in digital settings. Extending the implications of these findings, follow-up research can attempt to increase the range of applicability of the suggested framework to additional domains, e.g., e-learning, public service portals, and e-commerce sites. Furthermore, enhancing the participation of users with varying abilities and needs can lead to more representative and inclusive evaluation results. The other possible avenue of investigation is related to the expansion of the process model, which will support real-time feedback, continuous measurement of accessibility, and collaboration of stakeholders. Outside the scope of the given endeavor, the utilization of AI-supported strategies, and particularly those related to identifying the cracks in the context of subtle semantic or contextual issues, can be studied in the context of an additional optimization of routine examinations.

# Conclusion

Based on the performed research and comparison of current web accessibility evaluation tools and methods, the results highlight significant differences in their capabilities, indicating that combining automatic and manual assessments is essential for comprehensive accessibility evaluation. This approach ensures that both broad compliance issues and nuanced accessibility challenges are effectively addressed.

The proposed multi-layered evaluation method, which integrates automated tools, expert assessments, and user testing, was more effective in identifying a broader range of accessibility issues than any single method alone. The empirical analysis results corroborate that this integrated approach not only enhances coverage but also captures real-world usability issues that are essential for inclusive web design.

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