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CONCEPT OF AN AI-BASED SYSTEM FOR ENHANCING THE ACCESSIBILITY OF HOSPITAL WEBSITES

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ABSTRACT

Purpose: *The purpose of the paper is to present the concept of an AI-based system that automates the process of verifying and repairing accessibility errors on hospital websites. The system aims to ensure compliance with international WCAG standards and improve websites usability for individuals with various dysfunctions.*

Need for the study: *With the growing number of people with disabilities and the increasing role of the Internet as a source of information, website accessibility has become a key challenge in today's digital space. Hospital websites present a particularly critical challenge, as they serve as official platforms offering access to health information, medical services, and effective communication with facilities.*

Methodology: *The authors described the concept of a system in which artificial intelligence iteratively identifies and fixes accessibility problems to support web administrators creating and managing the hospital's website. Advanced technologies like convolutional neural networks, transformers, and models that combine natural language processing with computer vision are included.*

Findings: *The proposed system has the potential to significantly improve the accessibility of hospital websites, eliminating barriers affecting people with disabilities.*

Practical Implications: *The automation of accessibility processes using artificial intelligence not only saves time and reduces human errors but also counteracts social exclusion and increases inclusivity. The concept presented in the paper is a step toward full automation of accessibility enhancement, while supporting healthcare institutions in managing their websites in accordance with regulations and social responsibility.*

Keywords: digital accessibility, WCAG standard, hospital websites, artificial intelligence, machine learning, automation

Jel codes: L86, M15; O3; I18; C61

1.INTRODUCTION

With the rapidly growing number of people with disabilities and the ever-increasing role of the Internet as a significant source of information, web accessibility has become one of the key challenges of today's digital space.

Hospital websites, as official platforms of health units, serve a particularly important function, offering access to medical information, appointment registration and communication with facilities. Their role becomes even more important, given that more and more people seek health information online. In the context of existing legislation in most countries, such as laws governing digital accessibility, hospitals are obliged to ensure that their websites comply with international accessibility standards, such as WCAG (Web Content Accessibility Guidelines).

Despite these regulations and growing public awareness, research indicates that many hospital websites still do not meet accessibility requirements. These barriers mainly affect people with disabilities, for whom properly designed pages may be the only way to obtain necessary information. Against the backdrop of intense technological development, artificial intelligence can play a key role in automating and assisting the process of bringing websites into compliance with accessibility requirements, ensuring WCAG compliance and improving the user experience.

Ensuring the digital accessibility of websites is not only a matter of compliance but also a strategic element of management and marketing. Accessible websites increase the trust of citizens (in this case, patients), improve the institution's image, and enable better communication with diverse groups, counteracting social exclusion. They exemplify a modern approach to facility management that combines technology with social responsibility.

Traditional methods of improving accessibility, based on manual changes by website administrators, can be time-consuming, costly, and error-prone. In addition, the dynamically changing content of websites, as well as their expansion, requires constant review and updating, which poses additional challenges.

The purpose of this article is to propose a concept for a system that automates the process of validating and fixing digital accessibility errors on hospital websites. The proposed solution facilitates the efficient validation and adjustment of web pages to accessibility standards, while ensuring regular updates in response to evolving user needs. The article presents the concept of a closed-loop system operation, wherein the system iteratively modifies a page until no further changes are identified by the *Accessibility Validators* and *User Experience (UX) Evaluation Modules*. By leveraging artificial intelligence, the system can identify and fix issues that are difficult for traditional tools to detect, such as mislabeled images, illegible text, or navigation problems in dynamic elements.

The rationale for such a system stems from ensuring that hospital websites are fully accessible to a wide range of users, including people with disabilities, and the need for effective and efficient management of websites that often require updates and corrections. Using artificial intelligence to automatically analyze and improve accessibility saves significant time, reduces human error and ensures consistency with legal requirements, ultimately improving the quality of hospital services.

The system concept proposed in the article has been designed with the specific requirements arising from the nature of the information on hospital websites. Thus, the system considers the need to tag medical-specific elements such as medical images (e.g., X-rays, CT or MRI images) and medical diagrams, which often require a specific type of alternative descriptions. Moreover, the system is able to generate precise, contextual descriptions of these images, enabling patients with visual impairments to fully understand the visual content on the website. In addition, the system takes into account the fact that hospital websites often contain complex medical texts that may be incomprehensible to the layperson and therefore it is equipped with features to simplify texts, translate complex medical terminology into more accessible language, and adjust the level of difficulty of the content according to the potential user's needs and preferences.

2. LITERATURE REVIEW

Research is gaining increasing attention on web accessibility. Electronic media permeate almost every aspect of our lives, so ensuring equal access to information obtained through these channels is fundamental to inclusivity and social inclusion. Research in this area not only identifies barriers but also shows how to minimize exclusion, redress inequalities, and create a more equitable digital space for everyone.

In reviewing the literature in this area, initial reference was made to the eGovernment Benchmark 2023 Insight Report commissioned by the European Commission (Report of the EC, 2023). Although the analysis does not deal directly with hospital websites, but with the progress in the digitization of public services in Europe, the study is worth citing. The study covered 27 EU member states, plus countries such as Iceland, Norway, Switzerland, Albania, Montenegro, North Macedonia, Serbia and Turkey. It is a comprehensive study that, in addition to assessing digital public services in four key dimensions: User-Centricity, Transparency, Key Enablers and Cross-Border Services, it also identifies the most common errors found on the 15,000 e-government websites analyzed for digital accessibility. Many of these deficiencies can also be found on hospital websites, making this analysis relevant to the article's issue. Using the Axe tool (a browser extension), websites were evaluated against 8 of the 50 WCAG 2.1 criteria. The results indicated that the majority (82%) of public sector websites violate one or more of the 8 WCAG 2.1 criteria examined, which, of course, does not mean that the remaining 18% are compliant with accessibility requirements (as this would require checking all 50 success criteria). The most problems were revealed in terms of criteria related to:

Contrast (Minimum) (WCAG 1.4.3) – this is a criterion from the AA level; providing adequate contrast helps people with visual impairment, daltonism or elderly users to read text on the screen more easily; low contrast makes it difficult or even impossible to access information.

Link Purpose (In Context) (WCAG 2.4.4) – this is also an AA-level criterion and is concerned with ensuring that the purpose of each link can be determined from its content or related context. The content of the link should clearly inform the user of its purpose. Understandability of links is important for all users, but especially for those using assistive technologies such as screen readers. Such people can move between links on a page and hear only the link's content. Unclear links make it difficult for them to navigate and understand the website.

Parsing (WCAG 4.1.1) is an A-level criterion, which means it is one of the basic accessibility requirements. It refers to the correctness of a website's code, i.e. the correctness of HTML and CSS syntax, to ensure its compatibility with supporting technologies such as screen readers. Errors in the code can result in supporting tools not being able to correctly interpret the content of the website.

Non-text Content (WCAG 1.1.1) – is one of the fundamental requirements at Level A. This criterion focuses on providing text alternatives for all non-text elements (e.g., images – verbal description, videos – transcription, icons and buttons – labels) on a website.

According to the report, many websites of state institutions in Europe do not meet accessibility standards, which poses a challenge for some 60 million Europeans with various limitations. The document underscores the need to constantly strive to bring websites aligned with WCAG guidelines to ensure equal opportunities in accessing public services.

The following are the results of previous studies focused on the accessibility of medical institutions' websites. The growing number of publications in this area reflects the importance of e-health in providing services and medical information to patients. Selected results of studies conducted in the last few years are included, which gives a picture of the accessibility of healthcare entities' websites and their compliance with the recommended WCAG standards.

Kaur et al. (2017) assessed the accessibility, usability and security of hospital websites in metropolitan cities in India. They found that many websites had accessibility problems, and full compliance with WCAG guidelines was low. In addition, the websites of the hospitals surveyed neglected performance and quality criteria and, according to the researchers, needed many improvements to meet people's expectations and motivate them to use digital media for health-related information. Most websites lacked multilingual features, making it difficult to understand the content. Due to the CMS used (which was not updated regularly and had vulnerabilities), security also remained low.

Kuzma et al. (2017) conducted a study of international scope. Using the Tawdis tool, they analyzed 160 hospital websites in 16 countries on four continents. In all countries, they revealed a high prevalence of problems with meeting the WCAG standard, with Asian hospital websites having the highest incidence. Only two hospital websites included in the survey were fully compliant with Level A of the WCAG guidelines. The survey found that hospitals are not doing an adequate job of complying with accessibility standards and government regulations, thus depriving people with disabilities of the opportunity to fully use their websites.

Saghaeiannejad-Isfahani et al. (2019) presented similar findings after analyzing the websites of Iranian hospitals. They concluded that none of them were in the desired state. The researchers suggested that this was due to a lack of consultation with experts, a failure to follow design rules, and a lack of content management and website monitoring.

Sik-Lanyi and Orbán-Mihálykó (2019) tested the accessibility of nearly 100 health websites in nine European countries: the N-WE-EU group, which includes countries such as Germany, Switzerland, Sweden, Austria, Finland, and the V4 group, which included the Czech Republic, Hungary, Poland and Slovakia. They used AChecker and Nibbler tools for testing, as well as information obtained through interviews with website users. In their conclusions, they highlighted the most serious accessibility problems of the tested websites. The vast majority of them did not meet accessibility guidelines. According to the researchers, the errors were largely repetitive, common and easily avoidable. They mainly concerned criteria related to non-text content, contrast and text resizing. In many cases, the criterion related to correct structure, information and relationships between elements on the website, so that supporting technologies could interpret them correctly, was also not met. Interestingly, the researchers found no differences between the results of the N-W-EU and V4 countries. However, the GDP and GNI of the N-W-EU countries are significantly higher than those of the V4 countries.

Hospital websites in Saudi Arabia have also been examined for accessibility. Analyses using the AChecker tool were conducted by Alhadreti (2021). He focused on the websites of the top-rated 10 public and 10 private hospitals in Saudi Arabia. He found that only 20% of them fully complied WCAG 2.0. He found no significant difference in accessibility compliance between public and private hospital websites. The most commonly observed accessibility errors were in information structure, non-text content, labels and instructions, headings and keyboard access. The results show that most hospitals pay minimal attention to the accessibility of the content and structure of the information provided, which in the case of Saudi Arabia may be due to the country's failure to establish accessibility regulations and guidelines.

Against the background of previous studies, the evaluation of 91 infectious disease hospital websites in Poland was quite positive. According to the study's authors (Król & Zdonek, 2021), most of the websites appeared to be of satisfactory quality, but the results indicated strong variation among the websites in terms of search engine optimization, mobile-friendliness, and the needs of people at risk of digital exclusion.

Alajarmeh (2022) analyzed the public health websites of 24 different countries. The vast majority of them had many critical accessibility barriers, especially with regard to perceived information and handling of interface elements. At the A level, only five websites (from Italy, the UK, China, the Netherlands, and Brazil) and at the AA and AAA levels, only three websites (i.e., those belonging to Italy, the UK, and China) fully complied with the WCAG 2.1 standard.

An interesting study was conducted by Jonsson et al. (2023). They were interested in how healthcare providers in Sweden used accessibility claims on their websites. None of the providers fully addressed the requirements for accessibility statements, which means they did not meet the law's goal of providing accessible medical information and eHealth services. There was little or no progress between the first and most recently published accessibility statements.

Finally, the results of a study from Turkey and Malaysia. Macakoğlu and Peker (2023) examined the accessibility of 58 university hospital websites in Turkey. As in other countries, they revealed a low level of compliance with the WCAG 2.0 guidelines, with most of them not even meeting the minimum requirements for compliance level A. Almost all of the websites had broken links, and one-third had mobile device access problems.

Sarantis et al. (2024), in turn, surveyed the websites of 107 public and private hospitals in Malaysia against various criteria defined by the Health Sector Website Assessment Index (HSWAI). Most websites scored satisfactorily on the technology criterion and performed reasonably well in providing essential content but showed significant deficiencies in accessibility and community interaction. Compliance with the WCAG 2.0 standard at the AAA level for no website exceeded 16.8%, and for the weakest website, it was 0.9%.

A literature review identified significant deficiencies in the digital accessibility of websites, including those of hospitals, and the most common errors that limit their functionality. Before presenting the author's concept of a system using artificial intelligence to automate the work of ensuring the digital accessibility of hospital websites, the tools and methods currently used for this purpose were discussed.

3. TESTING DIGITAL ACCESSIBILITY OF WEBSITES

Automated tests are one of the most widely used tools in the process of checking the digital accessibility of websites. Although they cannot detect all errors and problems, they are worth using because of their speed and efficiency. They are helpful not only for accessibility auditors but also for the daily work of developers, designers, and testers. This is because they can be used at all stages of website maintenance, i.e. website creation, maintenance, evaluation and improvement.

The tools currently available differ in several key aspects (Colantonio, 2024; Pracownia Dostępności Cyfrowej LepszyWeb.pl, 2025):

The scope of tests: some of them analyze only single subpages (single web pages), while others can examine multiple pages or even entire websites at once (groups of web pages or websites).

Compliance: digital accessibility assessment tools can be used to test compliance with various WCAG levels (A, AA, AAA) or other standards (e.g., US Section 508 and ADA, French RGAA, Australian DDA, Canadian ACA or Italian Stanca).

Complexity: some tools have a very limited, specialized scope of operation and focus on one or a few functions (e.g., checking the correctness of headings, contrast or link accessibility). Others are more extensive, covering many aspects at once and combining multiple functionalities to offer a comprehensive approach to accessibility analysis, handling other formats in addition to HTML content, checking, for example, PDF documents or office application documents.

Users: tools of this type are created with different audiences in mind, on the one hand, some tools can be used by any ‘average’ Internet user, on the other hand, there are tools aimed at specialists (designers, programmers, content developers) that can be integrated with advanced software development systems and applications.

The level of detail in the results: tools can visually (by outlining, icon, comment) mark problematic areas on the page that need accessibility improvements, which enables analysis of the inconvenience in context and helps understand the relative importance of each problem. Other tools can generate simple reports that present synthetic results of the tests performed, based on a preset checklist, or more advanced and detailed reports that include, for example, paths to errors in HTML code and statistics on the problems detected.

Method of use: the tools can be available online via a website (online tools, online checkers), as extensions to authoring tools (authoring tool plugin), in the form of extensions to web browsers (browser plugin), in the form of web applications (desktop application) or mobile applications (mobile application) running under a specific operating system, but also as hosted services, regularly checking the website and providing reports.

Cost: you can find free and paid tools offered under commercial licenses.

The market has various automated digital accessibility testing tools that can filter by multiple criteria (W3C WAI, 2025; Colantonio, 2024). These include tools such as WAVE, AChecker, Free Website Accessibility Checker, Achecks, AccessibilityChecker, Utilitia, Tanaguru, and Lighthouse, allowing for multi-faceted accessibility assessment. Other tools evaluate selected accessibility elements, such as contrast (Color Contrast, ColorSafe, Contrast Checker) or markup correctness (HTML Validator, CSS Validator, Total Validator).

It's worth mentioning that because different tools often lead to slightly different results, there is an ongoing effort to unify the principles of accessibility testing (ACT, 2019). Documenting how accessibility requirements are tested will make accessibility testing transparent and test results repeatable. The Accessibility Conformance Testing rule format defines requirements for describing these descriptions.

It is also important to realize that even the most sophisticated accessibility testing tools available today cannot assess compliance of all aspects with the WCAG guidelines. Thus, the results of only an automatically performed assessment are mostly incomplete and require human judgment. The proposal presented in the article to incorporate AI into accessibility testing is intended to ease the auditor's burden and speed up adapting the website to the set criteria, ultimately without human involvement.

4. GENERAL SYSTEM FRAMEWORK

The system proposed in this article for automatization of the process of improving the accessibility of hospital websites consists of six main modules: *Accessibility Validators Module*, *User Experience (UX) Evaluation Module*, *Problem Classification Module*, *Automatic Repair Module, AI Repair Module*, and *Web Admin Module*. The connections between modules are illustrated in Figure 1, and their primary tasks are outlined in Table 1.

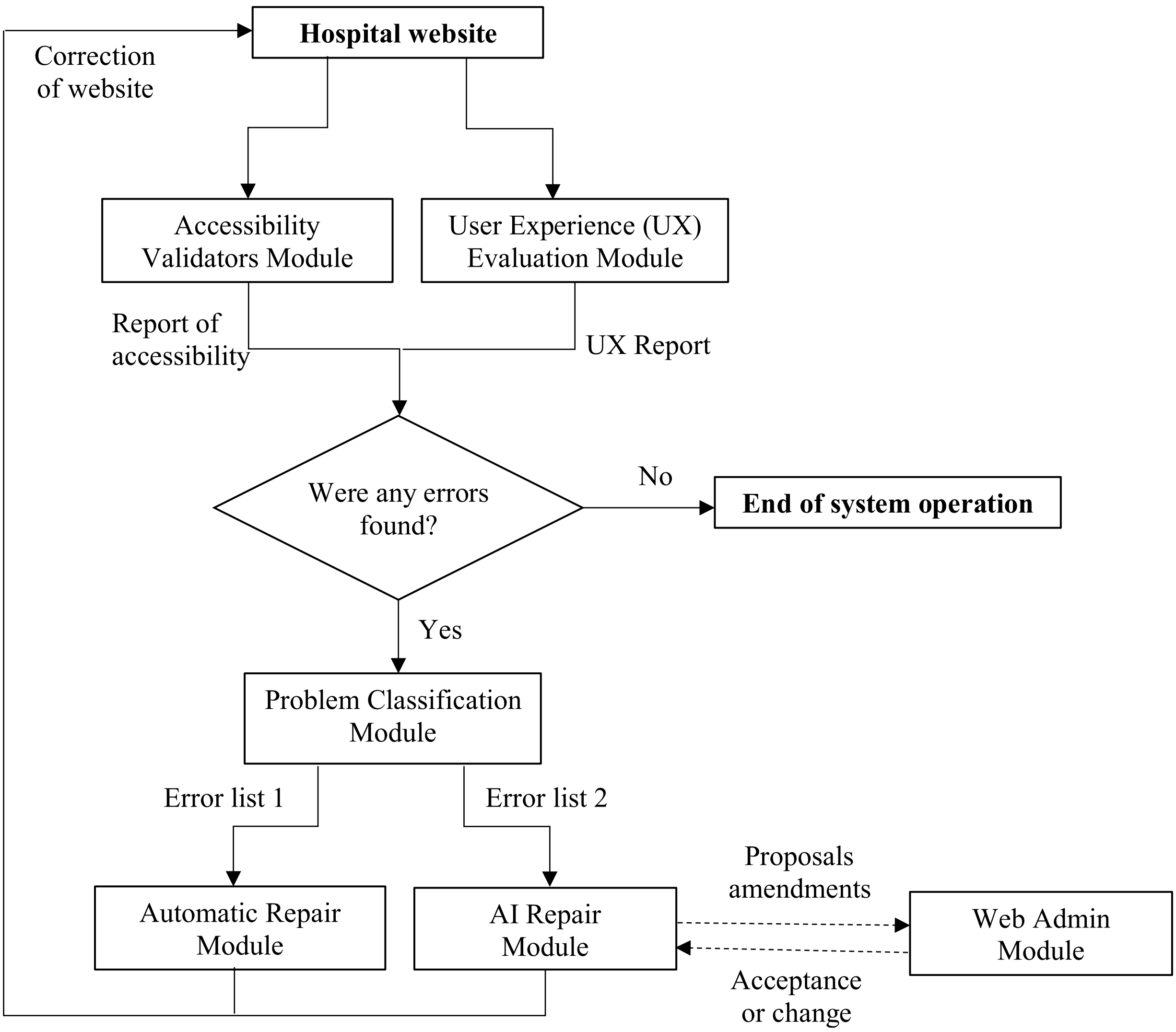

Figure 1. System architecture
Source: own elaboration.

The first stage of the system's operation involves conducting an accessibility audit of the website using a selection of the wide range of validators available, as discussed in the previous section. These tools generate reports that include a list of detected problems, such as a lack of alternate text for images, insufficient colour contrast, lack of visible markup for interactive elements, or incorrect navigation order. Also of particular concern for hospital websites are issues related to compatibility with assistive technologies, as well as ensuring that urgent messages are correctly labelled, such as in emergency situations.

A module that performs user experience (UX) evaluation is launched in parallel. This module works fully automatically and does not require user interaction, as its task is to simulate typical user paths using built-in artificial intelligence models. The system analyzes typical scenarios, including navigation through the structure of medical departments and interaction with dynamic content, such as test results. The analysis results in a second report identifying potential user difficulties, such as insufficient highlighting of active links, keyboarding errors or non-intuitive information hierarchy.

Both reports are then processed in the *Problem Classification Module*, which divides errors into two categories. The first includes standard problems that can be fixed using rules stored in the expert system's database. This group includes, for example, improper header structure, lack of proper labels for form fields and incorrect use of ARIA attributes. The second category includes non-standard problems that require artificial intelligence models. Examples include issues that require visual interpretation, such as generating descriptions for unsigned images or dynamically adjusting interface colours to meet contrast requirements.

Table 1. Tasks of each module of the system

Module name	Module task
Accessibility Validators Module	The module audits the website using tools dedicated to this purpose, detecting accessibility errors.
User Experience (UX) Evaluation Module	The module automatically analyzes user interactions, evaluating the user experience without human intervention.
Problem Classification Module	The module analyzes reports and divides errors into two categories: those that can be repaired automatically and those that require AI.
Automatic Repair Module	The module fixes standard accessibility errors with an expert system.
AI Repair Module	The module uses machine learning algorithms to generate solutions to more complex problems.
Web Admin Module	The module allows developers to monitor patches and accept changes generated by AI.

Source: own elaboration.

After the problems are classified, two lists of errors are generated. The first list, containing standard errors, is passed to the *Automatic Repair Module*, which makes corrections directly to the page code based on the expert system's rules. The system can, for example, automatically add missing 'aria-label' labels to buttons or correct the hierarchy of headings, providing a logical structure to the document. The second list, containing custom problems, goes to the *AI Repair Module*. Depending on the system settings, adjustments generated by this module can be automatically implemented or passed to developers for verification. An example of the operation of this part of the system could be a generative AI model, which analyzes image content and creates alternative descriptions in natural language, helping to meet WCAG requirements for multimedia.

Once the repair process is complete, the *Accessibility Validators* and *UX Evaluation Modules* are restarted to verify the effectiveness of the corrections made and to detect any new errors introduced by changes in the code. The system terminates if the reports provided by both modules show no further errors.

The presented concept makes it possible to significantly improve the accessibility of hospital websites, minimize barriers for people with disabilities, and ensure regulatory compliance. The system can act both as a tool to assist developers and as a fully automated platform for maintaining website accessibility.

4.1Accessibility validators module

The *Accessibility Validators Module* analyses a hospital's website for compliance with current accessibility standards. Most countries adopt WCAG (as of October 2023, W3C recommends version 2.2) as the baseline digital accessibility standard, the implementation and requirements of which are sometimes modified depending on local regulations and needs. The main task of the *Accessibility*

Validators Module is to detect technical problems that may impede the browsing of the website by people with disabilities, seniors or hospital patients using assistive technologies. For this purpose, validator tools present on the market can be used as mentioned earlier in this article. It is best to select them so that they complement each other in terms of functions and provide a comprehensive testing set, i.e. they identify both contrast or keyboard operation problems, detect HTML and CSS code errors, and allow evaluation of the semantic structure of the website, pointing out errors in headers, forms or multimedia. Other criteria, such as the scope of tests, compliance with standards, and the cost of implementation will also dictate the selection. Decisions on these issues should be made at the hospital's *Web Admin Module* level.

The module performs a holistic website analysis, identifying various categories of problems. The most common errors are those related to multimedia, including the absence of alternate text for images, which is important in the case of images informing about medical procedures, navigation pictograms or doctors' photos. For audio and video materials, the system checks for the presence of transcriptions and subtitles, which is particularly important for deaf people. Dynamic interface elements, such as system messages, are also analyzed and should be appropriately tagged in the code using ARIA technology.

Another important area of analysis is the problems related to navigation and user interaction. The system evaluates whether all key website functions are accessible via the keyboard, which is crucial for those who do not use a mouse. Navigational order is also checked so that users can logically move between website elements, such as registration forms. The correctness and accessibility of links are also verified, including whether they all work, are correctly described, and lead to the right places.

The analysis also covers readability and contrast problems. The system detects insufficient contrast between text and background, making reading difficult for people with poor eyesight. It also verifies that the website allows the font to be enlarged to at least 200% without losing functionality, which is crucial for the elderly and visually impaired.

Forms and patient registration systems are also important and should be intuitive and comply with accessibility standards. The module analyzes whether each form field has an appropriate label, whether interactive elements such as buttons are clearly marked, and whether error messages are clear and legible. It also checks whether fields can be auto completed, making it easier for users to enter data.

In addition to static page elements, the system also evaluates dynamic content, including notifications and changing interactive content. Key messages, such as information about changes in doctors' appointment times or test dates, must be appropriately marked in the code so assistive technologies can read them. The structure of headings on the website should be logical and organized, allowing easy navigation for those using screen readers.

After the analysis, the system generates a report summarizing the errors detected. The report includes detailed descriptions of the problems along with their location in the website code, as well as recommendations for fixing them, such as adding missing alternative texts, improving the structure of headings, or increasing text contrast. This report is then passed to the *Problem Classification Module*, which performs further analysis and evaluates which errors can be fixed automatically and which require developer intervention.

4.2 User Experience (UX) evaluation module

The *UX Evaluation Module* focuses on identifying problems that may hinder patients' and medical staff's interaction with the hospital's website. Its operation is based on using artificial intelligence methods to automatically simulate the user's interaction with the website and evaluate the clarity, intuitiveness, and efficiency of navigation. The module consists of five submodules, listed in Table 2, along with the type of problems they identify.

The module is based on deep learning models and natural language processing (NLP) techniques (Yang et al., 2018), as well as deep reinforcement learning algorithms (Arulkumaran et al., 2017) that learn from actual patterns of user interaction with a website. Transformer models such as BERT (Devlin et al., 2019) or T5 (Raffel et al., 2020) are used to analyze the structure and organization of content, evaluating readability and the logical arrangement of information on the page. For example, by analyzing button descriptions and form labels, these models can detect unclear wording that may confuse users. In addition, the module uses computer vision techniques, including Faster R-CNN (Ren et al., 2016) and YOLO (Redmon et al., 2016), to visually analyze the layout of elements on a page and assess their compliance with interface ergonomics.

In terms of evaluating navigation and user interaction, the module uses reinforcement learning techniques based on models such as Deep Q-Networks (DQN) (Mnih et al., 2015) or Proximal Policy Optimization (PPO) (Schulman et al., 2017). These algorithms learn by simulating real-world user actions, mapping patients' paths when registering for an appointment, searching for a doctor or reviewing test results. Based on these simulations, the system detects navigational barriers, such as the need to make excessive number of clicks, the lack of an intuitive section layout, or the difficulty in finding key functions such as registering for a doctor.

Table 2. Types of problems identified by each submodule of the *UX Evaluation Module*

Submodule number and task	AI methods	Problem identified
UXS1: analysis of the structure and organization of content	BERT, T5	Unclear wording and illogical information layout make it difficult for users, including people with disabilities, to find the content they need. Examples: The system detects that the "Save" button on the registration form is not clear; An analysis of the website's structure shows that information about the hospital's operating hours is scattered in various sections.
UXS2: analysis of the visual ergonomics of the interface	Faster R-CNN, YOLO	Suboptimal placement of elements on a page makes navigation difficult for people with limited visual perception. Examples: Visual analysis shows that the "Registration" button is low-contrast to the background, which can make it difficult to see. The system detects that key interface elements, such as navigation menus, are not evenly distributed across devices, which can cause problems for users of screen readers.
UXS3: evaluation of navigation and user interaction	DQN, PPO	Non-intuitive user paths lead to frustration and increased time to complete basic tasks. Examples: The system detects that the user must go through five unintuitive steps to sign up for an appointment. The interaction analysis shows that patients often abandon the process of searching for a doctor because relevant information, such as available appointments, is not presented intuitively.
UXS4: evaluation of alternative (alt) descriptions of images	CLIP	Inadequate alternative descriptions for graphics, making accessibility difficult for blind and visually impaired users. Examples: The system detects that an image showing a doctor at work has the description 'Image1.jpg'. Analysis of the chart with laboratory results indicates that the alternative description does not contain key information about the data presented.
UXS5: analysis and evaluation of content readability	BERT	Overly complicated language that makes it difficult for patients, especially the elderly and those without medical expertise, to understand the content. Examples: The system detects that the medical procedure description uses the term 'cholecystectomy laparoscopy' without explanation. analysis of the website's texts indicates that the sentences in the 'Patients' Rights' section are too long and contain many interjections, making them difficult to understand.

Source: own elaboration.

An additional functionality of the *UX Evaluation Module* is the analysis of the compatibility of alternative descriptions (alt) with the graphic content of images. Standard accessibility validators only check for the presence of alternative text without assessing its adequacy. To extend this functionality, the system uses artificial intelligence to analyze the content of images and compare them with the assigned description. This process uses the CLIP (Contrastive Language-Image Pretraining) model (Radford et al., 2021), which, due to being trained on image-text pairs, allows for the semantic analysis of image content in relation to text and is ideal for assessing whether the 'alt' description captures the content of the graphic. The system processes not only photos and images but also charts or diagrams, identifying the key objects and the relationships depicted (with the support offered by the YOLO model). Then, it evaluates whether the description matches this information.

In addition, the system evaluates whether the texts on the hospital's website can be understood by a wide range of users, including the elderly and patients without medical expertise. For this purpose, it uses the NLP (BERT) model to analyze sentence structure, paragraph length and vocabulary complexity. The model evaluates texts based on readability indicators, such as Flesch-Kincaid (Williamson et al., 2010), and then identifies passages that require simplification. In addition, the model detects sentences that are too long and complex, making it difficult to assimilate information quickly.

The final result of the *UX Evaluation Module* is a report containing detected problems and recommendations for their solution. The system can automatically suggest fixes, such as changing descriptions, rearranging elements, adjusting the content of labels or reorganizing the navigational structure to increase interface clarity. This report is then passed on to the *Problem Classification Module*, which determines which problems can be corrected automatically and which require developer intervention. Due to the use of artificial intelligence, the system enables dynamic and precise usability evaluation, adapting to the specific needs of hospital website users and supporting the optimization of their interaction with the system.

4.3 Problem classification module

The *Problem Classification Module* processes reports generated by the *Accessibility Validators* and *User Experience Evaluation* modules. Its main task is to analyze the detected errors, categorize them, and forward the relevant sets of issues to the *Automatic Repair Module* or, if the problem requires more advanced interpretation, to the *AI Repair Module*.

The classification process is based on simple heuristic rules and analysis of typical error categories. The system processes reports sequentially, assigning each detected problem to one of several predefined groups, such as:

- Technical errors (e.g., missing alt attribute, incorrect header hierarchy, missing labels in forms) that can be fixed automatically;
- Visual problems (e.g., too low contrast, suboptimal placement of interface elements) requiring involvement of the *AI Repair Module*;
- Content problems (e.g., unclear instructions, inconsistent nomenclature) also requiring involvement of the *AI Repair Module*.

If a given issue occurs repeatedly in different areas of the website, the system groups it within the same category, enabling more efficient decision-making regarding the repair method. Using simple classification rules, the module works quickly and does not require advanced artificial intelligence algorithms.

4.4 Automatic repair module

The *Automatic Repair Module* is responsible for implementing fixes to the website's code based on previously detected and classified standard errors. Its operation is based on an expert system that uses a knowledge base containing a set of predefined repair rules. Each of these rules describes how to solve a specific problem related to web accessibility based on accepted WCAG standard guidelines and best practices. The knowledge base can be expanded and updated continuously by developers through the *Web Admin Module*, allowing the system to be adapted to new technological challenges and the specifics of hospital websites.

The essential element of the module’s operation is to analyze the received list of errors and assign an appropriate repair rule to each problem. These rules take various forms – from simple instructions modifying HTML, CSS or JavaScript code to more complex operations involving the entire document structure. For example, suppose the system detects that the buttons on a page do not have proper markings for screen readers. In that case, it runs a rule with the following content: “For each ‘button’ element without the ‘aria-label’ attribute, check the text content, and if it is empty, add a description taken from the visible context (e.g., from the surrounding ‘label’ or iconography).” Similarly, if the page headers are used in the wrong order, the system applies a rule: “If a ‘h2’ header is followed by a ‘h4’ without an intermediate ‘h3’, change its level to ‘h3’.” In addition to a set of typical rules that improve page elements, the knowledge base also includes a prioritization mechanism for corrections that determines the order in which the rules are applied. In addition, the system supports conditional rules that consider a page's specifics. For example, for pages containing patient registration forms, the rules include verifying the presence of field labels and assigning them unique identifiers to ensure compatibility with assistive technologies.

The *Automatic Repair Module* also supports correcting errors related to navigation and interactivity. It can add missing 'tabindex' attributes for elements that should be accessible from the keyboard or remove redundant 'tabindex' values that could disrupt the correct order of transition between elements. For pages containing dynamic components, such as modal windows, the system ensures correct focus when opened and closed (in accordance with WCAG requirements).

For colour contrast problems, the module checks the relationship between the background and text and, if necessary, adjusts the colours to the minimum values specified by accessibility standards. For example, if a button with a light background has white text, the system automatically changes the text colour to a darker one.

The structure of the knowledge base also allows the definition of rules tailored to specific types of content. For example, for tables, the system enforces the use of column headers (‘th’ instead of ‘td’) and the assignment of the ‘scope’ attribute, which helps screen readers interpret the tabular structure correctly. For multimedia embedded on a page without audio and video content control mechanisms, the rules automatically include these mechanisms, allowing the user to pause and adjust the volume.

By using an expert system equipped with a set of rules with multiple levels of detail, the automatic repair module can effectively eliminate the most common accessibility errors, reducing the need for manual programming interventions and speeding up the process of making hospital websites WCAG-compliant.

4.5 AI Repair Module

The purpose of the AI Repair Module is to use advanced artificial intelligence methods to eliminate those errors that cannot be repaired by applying rules, contained in the expert system rule base of the Automatic Repair Module. Examples of such areas include more complex user interactions with website content, such as identifying and adjusting multimedia, understanding the context of texts, and improving the accessibility of dynamic elements that automatic tools may have difficulty interpreting. Like the first of the modules using AI methods, the UX Evaluation Module, the AI Repair Module also consists of several submodules, each designed to address a different type of accessibility problem (Table 3).

The first submodule (AIS1) deals with improving the accessibility of navigational content by automatically generating more relevant headings and precise text on user interface elements. It uses language models (BERT, T5) to analyze the content of page fragments and adjust section names, button labels and navigation menu descriptions to make them more intuitive and understandable to users. This corrects previously detected problems related to unclear names or unintuitive navigation structure. The submodule automatically replaces vague button descriptions, such as changing ‘Save’ to ‘Save patient data’, making it easier for users to understand the function of an item. In the case of headings, the system identifies their context and generates more descriptive versions – e.g., ‘Hospital opening hours’ appears instead of ‘Section 1’, and ‘Patient admission procedures’ instead of ‘Other information’. Navigation menus are also being optimized, with generic or vague terms such as ‘Department 1’ being replaced with more precise names, such as ‘Emergency Department’ or ‘Intensive Care Unit’.

Submodule AIS2 also deals with text analysis, but from a slightly different point of view. Its task is to analyze and simplify larger chunks of text flagged by the *UX Evaluation Module* as containing complex medical terminology that patients may not understand without proper training. This submodule also uses advanced language models, such as BERT or GPT, which, when adequately trained on medical data, can detect complicated terms and complex language constructs in medical texts. These models analyze the content on the hospital's website, identifying words or phrases that may be difficult for people without specialized knowledge to understand. Once difficult passages are detected, the system automatically generates simplified translations or definitions that are more accessible to many users. The generated explanations are aligned with general comprehension standards, eliminating the language barrier and ensuring that patients, even those without medical knowledge, can understand the content more easily.

Submodule three (AIS3) aims to improve the accessibility of visual content on hospital websites. To accomplish this task, the system uses pre-trained convolutional networks (such as EfficientNet (Tan et al., 2019) and ResNet (He et al., 2016)) that are further tuned on medical datasets. This approach makes it possible to accurately recognize elements typical of medical content in charts, diagnostic diagrams or images depicting patients' health conditions. Then, alternative descriptions are generated using the CLIP model, which enables semantic matching of textual content with image content, ensuring high relevance and detail. This submodule is used both to improve alternative texts identified as inadequate for the described content and in cases where such texts are completely absent.

The fourth submodule (AIS4) uses the Swin Transformer model (Liu et al., 2021) to analyze video frames and the VideoBERT model (Sun et al., 2019), also based on the Transformer architecture, to automatically generate a description of the video based on analysis of both video and audio. In addition, in the case of a previously identified lack of video transcription by the *UX Evaluation Module*, the system attaches a transcription generated using an automatic speech recognition package, the Whisper package (Radford et al., 2023), which has high transcription accuracy, even under difficult acoustic conditions such as background noise, different accents or fast speech.

Submodule AIS5 focuses on reducing the steps required to complete key actions, such as registering online, getting information about a medical service, finding a doctor, or downloading test results. It uses DQN and PPO reinforcement learning methods to analyze the sequence of actions that a user must perform, for example, to search for the desired information. Then it recommends their optimization by indicating the shortest path leading to their execution.

The task of the last submodule (AIS6) is to improve the layout of content on the website so that users can find key information more quickly and easily. To this end, it employs heuristic interface analysis algorithms and image processing methods. Heuristic interface analysis, based on the PageRank metric calculated for individual subpages and their sections, allows for determining which elements of the website are most important and should be placed in more prominent positions. At the same time, image processing models, such as Faster R-CNN, analyze the visual structure of the website, detecting potential problems with the layout of elements, such as non-intuitive button placement or excessive density of text. In addition, by analyzing the HTML and CSS structure, the submodule suggests changes to the navigation so that key information is placed in easily accessible locations and minimises content distraction.

Table 3. Submodules of the *AI Repair Module*

Submodule number and task	AI methods	Problem solved
AIS1: improving the accessibility of navigational content	BERT, T5	Overly general or vague wording on user interface navigation elements. Examples: Changing the non-intuitive name of the 'Save' button on the registration form to 'Save patient data' Adjusting the header of the patient registration information section to match its content, changing from 'Other information' to 'Patient registration information'
AIS2: simplifying and translation of medical terminology	BERT, GPT	Complicated medical terminology that is incomprehensible to a wide range of patients. Examples: The system replaces the term 'adjuvant radiotherapy' in the description of patient recommendations with a simplified definition of 'Treatment with radiation given after surgery to lower the chance of the disease coming back' The system replaces the study description: 'A patient with a diagnosis of advanced-stage COPD, accompanied by hypoxemia, requires immediate stabilization of respiratory function and compensation of electrolyte disturbances, especially hypokalemia' with a simplified version: 'A patient with advanced lung disease has an excessively low oxygen level in their blood and needs immediate respiratory improvement and potassium equalization'

AIS3: improving the accessibility of visual content	EfficientNet, ResNet, CLIP	Inadequate or missing alternative descriptions for images and visual content. Examples: The system adds a missing alternative description for the chart of laboratory results: ‘A graph showing changes in a patient's blood glucose level during treatment’ The system replaces the overly general description of the medical diagram ‘Medical diagram 1’ with a description referring to the contents of the diagram ‘Diagram showing the distribution of organs in the human body including the circulatory and respiratory systems’
AIS4: improving video accessibility	Swin Transformer, VideoBERT, Whisper	The lack of alternative descriptions/transcriptions for videos or descriptions/transcriptions are inadequate for the content presented. Examples: Adding a transcription to a video showing a medical procedure; Changing the overly general alternative description ‘Medical lecture’ to a description that refers to the content presented: ‘Lecture on new cancer treatments, discussing chemotherapy and immunotherapy treatment techniques’
AIS5: optimization of user paths	DQN, PPO	Non-intuitive or suboptimal user paths. Examples: The system recommends reducing the number of steps required to sign up for an appointment from five to three, removing two of them that do not provide relevant information; In order to reduce the number of abandonment of the process of searching for a doctor by users, the system proposes to move information about available appointments directly to the search results, which shortens the interaction path.
AIS6: reorganization of information	PageRank Faster R-CNN	Suboptimal distribution of content on the website. Examples: The system suggests moving the hours of operation of the hospital's departments scattered across individual subpages to one central section on the home page or a dedicated subpage; The system proposes changing the order of sections and reducing the number of fields in the registration form, reducing the need to scroll through it and shortening the time of filling it out.

Source: own elaboration.

4.6 WEB MODULE ADMIN

The *Web Admin Module* provides full control over the process of implementing corrections on the hospital website, enabling both the management of automatic repair rules and the approval of changes suggested by artificial intelligence. The administrator can supplement and edit the expert system's knowledge base, which makes customization of the system flexible and precise.

One of the module's key features is the ability to specify the repair mode. That means that the administrator can decide whether the changes suggested by the AI algorithms should only be recommended and require manual approval or whether they should be automatically implemented on the website. In the initial phase of the system's operation, it is recommended to use the patch acceptance mode, as this allows the AI models to continuously learn from the administrator's decisions. Human verification provides the system with feedback on the quality of suggested changes, which allows the algorithms to better adapt to the actual needs of the website's users.

Once the system becomes sufficiently effective, the administrator can switch it to full automation mode, eliminating the need to manually approve each adjustment. In this mode, the artificial intelligence models no longer receive feedback, and the tuning process is stopped. However, if re-optimization of the system's operation is required, it is possible to restore the manual approval mode, which will restart the process of tuning the models based on the administrator's interactions.

With the *Web Admin Module*, patch management becomes flexible and adaptable to the hospital's changing needs. The system allows a gradual transition from supervised implementation of changes to full automation, while providing comprehensive control over content organization and website navigation.

5.CONCLUSION

Today's hospital websites play a key role in providing patients access to health information, medical services and communication with staff. However, despite technological advances, many hospital websites do not fully meet accessibility requirements, which poses a serious challenge for people with various disabilities. According to current legislation, these websites should be accessible to all users, including those with visual, hearing, motor or cognitive impairments. Inadequate accessibility of websites can lead to difficulties in accessing medical information, negatively affecting the quality of health care and equality of access to services.

Technological advancements and the development of artificial intelligence are creating new opportunities for ensuring web accessibility. While helpful, current tools have limitations – they cannot detect or correct all inconsistencies with the WCAG standard. Moreover, they require human labour and manual testing, which significantly lengthens the process of auditing and correcting websites, making it more expensive.

The concept of the system proposed in the article is based on the use of AI to achieve full automation in ensuring accessibility, while supporting designers and developers from the early stages of website development. By integrating advanced artificial intelligence, computer vision and context-sensitive tools, the system has the potential to significantly increase the widespread accessibility of hospital websites in a short period of time. Nowadays, despite rapid technological advances, there is still no solution that completely eliminates the need for human verification when testing and ensuring website accessibility. The proposed system is a step in this direction, effectively reducing barriers to information access, increasing inclusiveness, ensuring equality and reducing social exclusion.

The growing number of studies and publications in this area, following years of the Web Accessibility Directive, also indicates that these issues are finally receiving more attention and interest, along with the expected increase in awareness.

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