

WEBSITES WITH VIRTUAL CHURCH TOURS IN POLAND – USABILITY AND ACCESSIBILITY ANALYSIS

Michał Mitura, Mariusz Dzieńkowski

Lublin University of Technology, Department of Computer Science, Lublin, Poland

Abstract. The purpose of this work was to analyze usability and evaluate the level of accessibility of websites that offer virtual tours of churches in Poland. Five websites were assessed: the Basilica of the Holy Sepulchre in Miechów, the Cathedral Basilica of the Assumption of the Blessed Virgin Mary in Kielce, the Minor Basilica in Gorlice, the Gniezno Cathedral, and the Evangelical-Augsburg Parish in Sorkwity. The study was conducted in three stages: using an extensive checklist dedicated to ordinary users and multiaspect evaluation of selected virtual churches, four automated tools for checking accessibility, and an expert checklist. The results of the conducted research showed both strengths and areas of improvement in the services analyzed. Significant differences in accessibility and usability levels were revealed between the various virtual walks. Virtual churches offer users a variety of experiences, but not all fully meet accessibility standards, which can be a barrier for some users, including people with disabilities. The results point to the need for further improvement of the sites, especially in terms of intuitive interfaces, readability of content, and compliance with WCAG guidelines. The data collected can provide a useful knowledge base that can be used to improve the quality of virtual tours and better adapt them to the needs of modern audiences.

Keywords: virtual churches, virtual tours, usability analysis, accessibility analysis

WIRTUALNE KOŚCIOŁY W POLSCE – ANALIZA UŻYTECZNOŚCI I DOSTĘPNOŚCI

Streszczenie. Celem niniejszej pracy była analiza użyteczności i ocena poziomu dostępności stron internetowych oferujących wirtualne spacerunki po kościołach w Polsce. Ocenie poddano pięć serwisów: Bazylikę Grobu Bożego w Miechowie, Bazylikę Katedralną Wniebowzięcia Najświętszej Maryi Panny w Kielcach, Bazylikę Mniejszej w Gorlicach, Katedrę Gnieźnieńską oraz Parafię Ewangelicko-Augsburską w Sorkwity. Badanie zostało przeprowadzone w trzech etapach: przy użyciu rozbudowanej listy kontrolnej dedykowanej zwykłym użytkownikom i wieloaspektowo oceniającej wybrane wirtualne kościoły, czterech narzędzi automatycznych do sprawdzenia dostępności oraz eksperckiej listy kontrolnej. Wyniki przeprowadzonych badań wykazały zarówno mocne strony, jak i obszary wymagające poprawy w analizowanych serwisach. Ujawniono znaczące różnice w poziomie dostępności i użyteczności między poszczególnymi wirtualnymi spacerunkami. Wirtualne kościoły oferują użytkownikom różnorodne doświadczenia, jednak nie wszystkie spełniają w pełni standardy dostępności, co może stanowić barierę dla części użytkowników, w tym osób z niepełnosprawnościami. Wyniki wskazują na konieczność dalszego udoskonalania serwisów, szczególnie w zakresie intuicyjności interfejsów, czytelności treści oraz zgodności z wytycznymi WCAG. Zebrane dane mogą stanowić przydatną bazę wiedzy, która może być wykorzystana do podnoszenia jakości wirtualnych spacerunków i lepszego dostosowania ich do potrzeb współczesnych odbiorców.

Słowa kluczowe: wirtualne kościoły, wirtualne spacerunki, analiza użyteczności, analiza dostępności

Introduction

The development of technology, the increase in the availability of the Internet, and the desire to reach a growing audience mean that more and more institutions, including religious ones, decide to create virtual spaces that allow online exploration of sacred buildings. One such solution is virtual walk-throughs of churches, which allow visitors to visit regardless of the user's location. Such initiatives are implemented using various technologies, such as spatial scanning and photographic techniques, which enable faithful reproduction of the architectural details and atmosphere of these places. However, for websites offering virtual tours to be fully functional, they must be both useful and accessible to all users, including people with disabilities. Usability here means the system's ability to effectively, efficiently, and satisfactorily support the user in achieving its goals. Accessibility, according to the Web Content Accessibility Guidelines (WCAG) standards [13], is a key element in the design of user-friendly interfaces. In the context of virtual tours, ensuring a high-quality user experience becomes not only a technological challenge but also a social one, aiming to include all stakeholders, regardless of their physical or technological limitations. Virtual tours are not only a modern tool for promoting cultural and religious heritage, but also a way to build social bonds and enable a spiritual and educational experience for people who, for various reasons, cannot visit these places in person.

The research conducted and described in this article will allow an assessment of the current state of these websites and the identification of areas requiring improvement, providing guidelines for developers and administrators of such websites. The purpose of the work is to analyze the usability and assess the accessibility level of five websites that offer virtual tours of churches in Poland. The scope of the paper includes a review of the literature on usability research, website accessibility, and space virtualization. The theoretical introduction includes issues related to accessibility and usability requirements and standards, tools used for accessibility and usability research,

ways to virtualize space, and an overview of virtual churches. The research part consists of a description of the research methods used, the selection and characteristics of five websites offering virtual tours along with information on the technology used to create them, a description of the research stand, a presentation of how the research and data acquisition were carried out, an analysis and discussion of the obtained results, the formulation of conclusions, and the proposal of good practices.

The two research hypotheses were formulated as part of the study:

H1: *Virtual tours of churches in Poland only partially meet accessibility requirements.*

H2: *The level of usability of virtual walks is varied and depends on the technology used and the method of implementing key interface functions.*

1. Related works

This review includes literature items on the broad topic of virtual tours, exhibitions and museums, the research methods used to evaluate websites offering tours via the Internet, and the issues of usability and accessibility in the context of such websites.

In the article [7], the authors explore the growing interest in digitizing collections to preserve cultural heritage and make them more accessible to a wider audience. The article highlights how technologies such as virtual reality (VR), augmented reality (AR), and Web3D are transforming museum experience by creating virtual walks accessible via online platforms. The authors analyzed the technological tools used to create these virtual spaces, including imaging technology, VR, AR, and haptics (interaction through the sense of touch), discussing their advantages and limitations. While virtual museums offer interactive and engaging experiences, they cannot completely replace physical museums but serve as valuable complementary platforms. The paper also discusses challenges such as high development costs, digital skills requirements, and the potential



for false presentation, emphasizing the need for careful integration of these technologies to enhance the museum experience.

In the article [5], the authors present a methodology for documenting and protecting cultural heritage buildings through 3D digitization. The study used advanced tools such as terrestrial laser scanning (TLS) and close-range photogrammetry to create accurate and photorealistic models of historic sites at risk of destruction or demolition. St. Adalbert's Church in Chicago, a historically significant building facing deterioration, served as a case study. The process involved generating a point cloud and a mesh model, consisting of 3.5 billion points, as well as a mesh model consisting of 1.6 billion triangles. Documentation not only supports conservation, but also enables virtual exploration and research applications, contributing to wider access and preservation of cultural heritage.

In the article [1], the authors present a comprehensive methodology for creating virtual exhibitions of archaeological finds. The approach integrates realistic 3D reconstructions, created using 3D scanning and high-resolution photography, with an innovative stereoscopic visualization system called MNEME. The applied method responds to challenges such as the accessibility, portability, and cost-effectiveness of virtual reality systems in cultural heritage.

In the article [6], the authors analyzed the impact of universal design on the usability of movie-related websites. The study compared an existing FilmWeb website with an author's website, focusing on the effectiveness of universal design principles. The methods included eye tracking, questionnaires, and validation tests to assess WCAG and W3C compliance. Ten participants aged 23-25 took part in the study, who evaluated elements such as navigation, readability, and structure. The results indicated that universal design principles significantly improved usability and accessibility, and the FilmWeb interface shows more problems compared to the nonstandard design. The authors concluded that universal design not only improves user experience, but also ensures compliance with the accessibility requirements of websites.

In the article [4], the authors analyzed user experiences in virtual museums. At the beginning, two museums were presented as research objects: the Auschwitz-Birkenau Museum and the Malbork Castle Museum. The authors explain that the interfaces of these museums were evaluated using three methods: eye-tracking analysis, expert analysis based on Nielsen heuristics, and a survey combining the System Usability Scale (SUS) with non-standard questions. The research group consisted of 16 students from Lublin University of Technology, who were asked to perform the same tasks in both virtual museums. The results showed that according to Nielsen's heuristics and the SUS survey, the Auschwitz-Birkenau Museum interface was rated better, while eye-tracking analysis showed similar task performance in both museums.

2. Accessibility and usability requirements and standards

The World Wide Web Consortium (W3C) organization [3] is responsible for setting standards for creating and publishing content on the Internet. The organization currently includes more than 400 different entities, including companies, organizations, and scientific institutions. In 1997, the W3C established an initiative called the Web Accessibility Initiative (WAI), whose main task is to improve the accessibility of websites to make them more accessible to people with disabilities and those at risk of digital exclusion.

WCAG 2.1 [2] is a set of guidelines that define the principles for creating accessible websites, which can be found on the W3C website. The standard is based on four key principles:

- perceivability – information and user interface components must be presented in such a way that they are accessible to users' senses,
 - functionality – navigation and user interface components should be intuitive and easy to use,
 - understandability – the user interface and content on the site must be clear and understandable,
 - compatibility – proper interpretation by assistive technologies such as screen readers.
- However, accessibility alone does not guarantee that a website is user-friendly [14]. Therefore, an equally important aspect, complementing accessibility requirements, is usability, which refers to the overall ease and efficiency with which users can use websites. Services must be not only accessible to a wide range of users, including people with disabilities, but also intuitive to use and effective in their operation. Many experts in the field of website usability have studied issues related to the ergonomics and functionality of online websites, trying to determine the important features that affect their usability. One of the most recognized specialists in this field is Jakob Nielsen, who defines usability as the most important element of quality, based on ease of use. He distinguished five key factors that affect the quality of a user's experience on a website:
- learnability – determines how easily users can learn how to use the website, which has a direct impact on the time needed to master the basic functions of the website,
 - efficiency – refers to the speed at which users can complete their tasks on the website, which affects their overall performance,
 - memorability – refers to the ability of users to easily remember how to use the website after a certain period of time, making it easier for them to revisit the website,
 - satisfaction – determines the level of satisfaction of users when using the webservice and expresses their overall attitude towards the website and how satisfied they are with its performance,
 - errors – refers to the number of errors made by users while using the website, which helps to assess how error-free and correct the website is in everyday use.
- The aforementioned aspects form the foundation of a website's usability evaluation, affecting how positive and effective the user experience is.

3. Material and methods

The study included preparation and conduct of an experiment that consisted of three parts: a user survey developed by the authors, research with automated tools, and expert analysis. Each of the studies referred to the research material – five websites that offer virtual tours of churches in Poland.

The first part of the study was made on the basis of a checklist, the content of the 22 issues raised is shown in table 1. The survey can be divided into five parts which, respectively, concern:

- Interface (red box in figure 1) – including the navigation elements, menus and options at the edges, and the layout of these objects within the virtual tour of the church. The walk itself or the content provided within it should not be taken into account here.
- Screen (yellow box in figure 1) - which includes dynamic elements located in the area of the virtual tour window, which include icons, hanging tags, navigation elements, or textual information about important objects constituting the equipment of churches.
- Terminology, messages and errors – consistency of names across the site, where messages are displayed, error reporting, and error fixing assistance.
- Learning – easy memorization of concepts and content as well as support in the process of getting to know a new virtual environment enabling pleasant exploration.
- Performance, reliability, and trouble-free operation for the widest possible group of users.

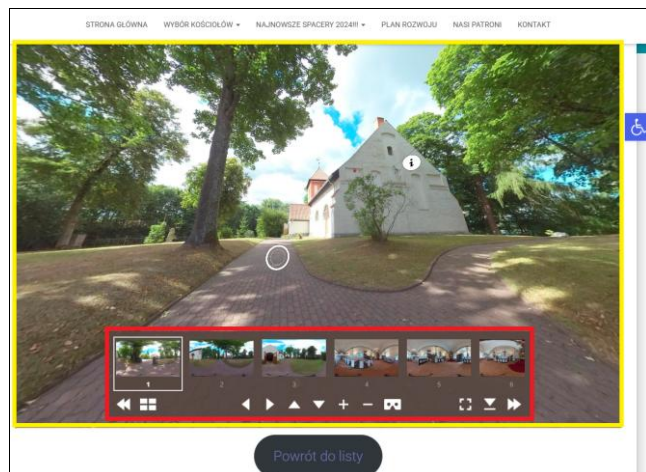


Fig. 1. Graphical interpretation of the Screen and the Interface areas

Before completing the checklist, participants had to have a minimal familiarity while each virtual church was evaluated by completing two simple tasks. The first task was the same for each virtual tour and involved of reaching the altar using arrows, the search engine or the bottom menu. The second task was tailored to the specifics of a given church and involved using a search engine to find an important object in a given church, such as a door or cloister, getting to the choir by looking at the church from a bird's eye view and finding information about the year the organ was built.

The assessment of each aspect in the checklist was expressed on a scale of 1 to 10, where extreme values, depending on the content of the issue, could mean, respectively: terrible – great, difficult – easy, boring – stimulating, discouraging – encouraging, etc. The choice of a ten-point scale allowed for a detailed and multifaceted evaluation of the quality of virtual church interfaces by users.

Table 1. Checklist examining various aspects of virtual church interfaces

No.	Aspects assessed	
1	Overall evaluation of the interface.	Interface
2	Evaluation of interface difficulty.	
3	Evaluation of user satisfaction.	
4	Evaluation of interface performance (smoothness of operation).	
5	Evaluation of emotional arousal caused by the interface.	
6	Evaluation of the appearance of the interface.	Screen
7	Evaluation of the level of difficulty in reading text.	
8	Evaluation of assistance in identifying an item by highlighting it.	
9	Evaluation of the organization of information on the screen.	
10	Evaluation of the level of difficulty when moving between screens.	Terminology
11	Evaluation of the consistency of use of terms throughout the system.	
12	Evaluation of the consistency of the location of messages on the screen.	
13	Evaluation of the usefulness of error messages.	
14	Evaluation of the level of difficulty in fixing your own errors.	Learning
15	Evaluation of the difficulty of learning to use the site.	
16	Evaluation of difficulty when discovering new features.	
17	Evaluation of performing actions on the site.	
18	Evaluation of the level of difficulty in remembering names and using commands.	Performance
19	Evaluation of the usefulness of messages that help the user.	
20	Evaluation of the fluidity of the system operation.	
21	Evaluation of the reliability of the system operation.	
22	Evaluation of whether the designed system is suitable for different levels of users in computer operation and Internet use.	

In the second part of the experiment, automatic tools were used to assess the accessibility of websites. The evaluation included websites that contain virtual tours of churches. The automatic tools expressed the final level of accessibility in numerical form.

To make the results objective, each page was evaluated using four automated tools: ACE, Lighthouse, MAUVE++ and Utilitia.

These tools meet the following criteria:

- analysis of websites according to the WCAG standard,
- free access and the ability to analyze single pages or entire websites,
- possibility to run in online mode,
- generating an overall rating expressed in numbers (points or percentages) defining the level of website accessibility.

The third part of the study included an expert analysis, which was performed using a specially constructed checklist of 14 questions on various aspects of interface quality (table 2). Two experts with knowledge and skills in human-computer interaction, universal design in IT, and barriers in the digital space participated in this study. First, their task was to familiarize themselves with the assessed website that contains a virtual tour of the church and then provide binary responses to the checklist questions. In this way, all 5 services were analyzed.

Table 2. Expert checklist for assessing interface quality

No.	Content of the question
1	Is the website interface intuitive and easy to navigate?
2	Is the site layout consistent, logical, and aesthetically pleasing?
3	Does the site offer a mobile version of the site and automatically adjust to different screen sizes?
4	Is the page load time adequate?
5	Does the site provide smooth operation during the virtual tour, with no technical interruptions (e.g. delays, jams)?
6	Does the website include accessibility tools such as audio transcriptions, subtitles, or keyboard controls?
7	Are interactive elements (buttons, links) easy to identify?
8	Does the website include a search engine and is it easy to use and provides relevant results?
9	Are users able to quickly and easily learn how to use the site, even if they have not experienced it before?
10	Is the virtual tour offered by the website interactive, providing the ability to freely move through the virtual space?
11	Is the image quality of the virtual tour high enough?
12	Does the service offer additional information, such as object descriptions, audio or video narratives, that enhance the experience?
13	Is navigation during the virtual tour intuitive, allowing for easy movement?
14	Does the site include supplementary materials or interactive elements, such as quizzes, educational games, or additional multimedia?

3.1. Research subjects

The research material included five websites offering virtual tours of churches in Poland. When selecting these services, the main consideration was that each of them was to be made by a different company and using different development techniques, such as panoramic photos, 3D scanners or drones. All services differ in their interface and the way they place additional content. Some of them have an audio track, narrator, and facilities for people with disabilities. The main selection criterion was clear differentiation in the design of virtual tour interfaces. For the purposes of the study, the websites that allow virtual tours were chosen:

- 1) The Cathedral Basilica of the Assumption of the Blessed Virgin Mary in Kielce [9] (abbreviated BKW), made by *Paweł Jarzębiński E-kontakt*, technology: panoramic 360°.
- 2) The Cathedral of the Assumption of the Blessed Virgin Mary and St. Adalbert in Gniezno [10] (abbreviated KG), made by *Sotis Studio*, technology: laser scanning and structured light and gigapixel photography.
- 3) The Minor Basilica of the Nativity of the Blessed Virgin Mary – Gorlice [12] (abbreviated BM), made by *Show3D.pl*, technology: 3D scanning enhanced with photos and videos taken with a professional camera and drone.
- 4) The Basilica of the Holy Sepulchre in Miechow [8] (abbreviated BGB), made by *ai360*, technology: spherical photography.
- 5) The Evangelical Augsburg Parish in Sorkwity – Church in Rasza [11] (abbreviated PEA), made by *Evangelical Augsburg Parish in Kętrzyn*, technology: 360° filming/photography.

3.2. Research stand

An experiment was conducted that consisted of three independent studies: user assessment, expert analysis, and testing with automated tools. The user study was conducted using a questionnaire made available online on the Google Forms platform and therefore could be filled out by anyone interested. The participants evaluated various aspects of their devices.

The expert analysis was conducted by two independent experts who had knowledge, skills, and experience in the field and had previously undergone relevant courses. Experts gave ratings on 14 questions from a checklist. Then their ratings were agreed upon by them.

The analysis using automated tools was performed on a mid-range desktop computer with Internet access. Four online available automatic tools were used: ACE, Lighthouse, MAUVE++, and Utilitia. The results collected were subjected to basic statistical analysis and allowed us to determine the level of accessibility of a given service that allows virtual tours.

4. Results and discussion

4.1. User analysis

For each virtual church, a separate user survey was conducted to evaluate it using a checklist. A different number of responses were collected: for BGB, it was 40, BKW – 50, BM – 62, KG – 50 and PEA – 36 responses.

The number of subjects participated in the study is difficult to determine, because some of them participated in evaluating more than one virtual tour. The results for each category (table 1) in the form of an arithmetic mean of the ratings given by the participants are shown in figure 2 using a percentage scale.

In the group of issues related to the Interface, the highest score was obtained by the BKW virtual tour (86.10%), which was influenced by the high level of user satisfaction with the layout and functionality of the interface. On the other hand, the BM walk, received the lowest score (70.00%), due to difficulties related to the intuitiveness of use and the layout of the interface. The other virtual tours (BGB, KG, PEA) achieved results of 78–80%, which also indicates the high quality of their interfaces.

In the Screen category, the PEA virtual tour received the best rating (89.45%), indicating its good readability of content and organization of information on the screen. On the other hand,

the BM walk, achieved a low score of 72.66%, indicating the need to improve the readability and layout of the information. The other three virtual walks also achieved satisfactory results in the range of 83–88%.

In the group of issues concerning terminology, messages, and errors, the PEA virtual tour achieved the highest score (91.11%), and therefore is characterized by high consistency in the terms used and clarity in the messages generated. On the contrary, the virtual church BM achieved the lowest score (79.80%), which means that the terminology may have been less intuitive or inconsistent. The other evaluated walks achieved scores greater than 84%, indicating good consistency and relevance of the terminology used.

In the group of aspects related to Learning, i.e. easy memorization of concepts and content, PEA (92.28%) and BGB (91.05%) walk achieved similar highest scores, indicating that exploration of these virtual churches was easy and intuitive for users. BM received the lowest average score (73.26%), which may suggest that this website was more complicated to use. The other virtual tours also performed well, scoring above 87%. In the group of aspects pertaining to Learning, i.e. easy memorization of concepts and content of the walk, PEA (92.28%) and BGB (91.05%) received similar highest scores, indicating that exploration of these virtual churches was easy and intuitive for users. BM received the lowest average score (73.26%), which may suggest that this site was more complicated to use. The other virtual tours also performed well, scoring above 87%.

In terms of performance, reliability, and trouble-free operation for the widest range of users, the PEA virtual walk received the highest score (93.98%). This service was characterized by smooth operation and was designed so that users did not make errors. The lowest score in this category was achieved by the BM walk (74.95%), as there were problems with its smooth operation or its adaptation to different user groups. The remaining virtual churches achieved scores ranging from 87% to 93%.

The total results for each virtual tour were calculated as the arithmetic average of the scores obtained from the 22 issues that comprise the user checklist.

Figure 3 shows that the highest average score was achieved by the PEA virtual walk (89.09%), indicating a very high overall quality and a very highly rated user experience. Clearly, the lowest overall score will be achieved by the BM tour (74.13%), which means that it needs to make several improvements. Virtual walks: BGB, BKW, and KG also achieved high overall scores of 85–88%, indicating their high quality and highly rated user experience.

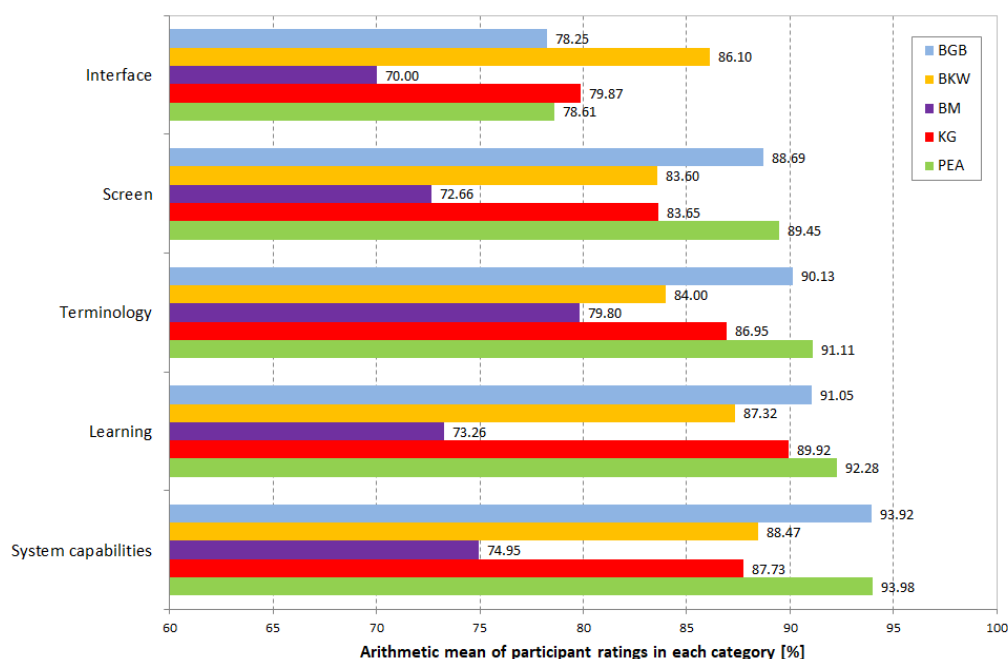


Fig. 2. Averaged scores for groups of checklist items rated by respondents

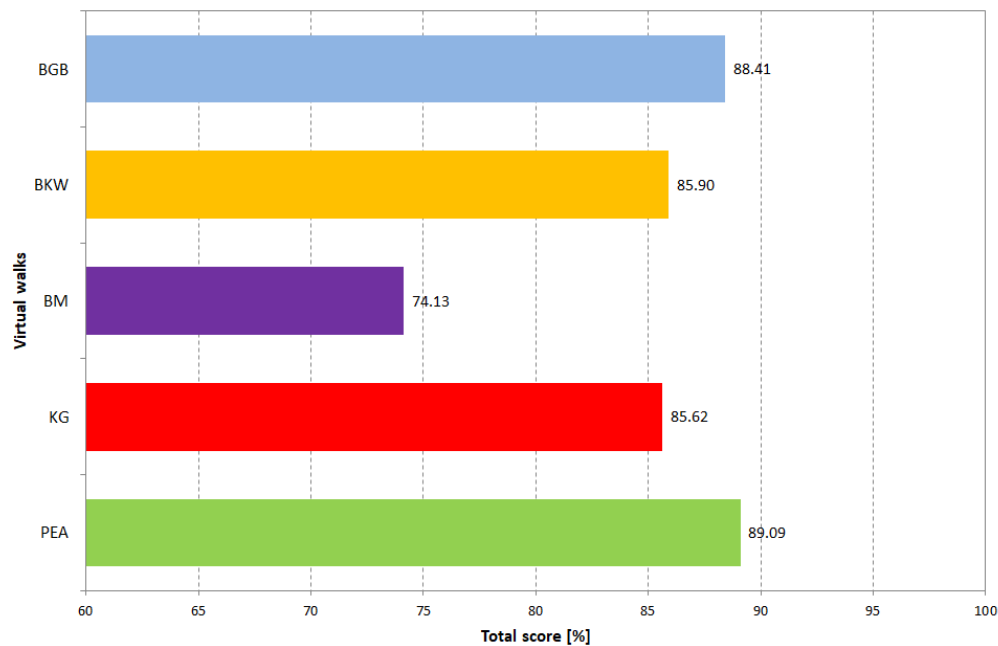


Fig. 3. Generalized evaluation of the individual virtual churches studied

4.2. Accessibility testing with automatic tools

The results of the automated tools are presented in figure 4. According to the Utilitia tool, the PEA website achieved the highest accessibility score of 93%, while the BKW website had the lowest score of 54%. The remaining BM and BGB web services scored 80% and 82%, respectively. The Utilitia tool generated a large number of warnings, mainly related to CSS validation issues and link accessibility. According to the ACE tool, the PEA website received the highest score, with 93%, while BKW received the lowest result of 59%, indicating serious problems, such as a lack of proper labels in the forms. The KG website achieved a rating of 88%, while BGB and BM received lower scores of 84% and 73%, respectively.

According to the Lighthouse tool, the BM webpage achieved a score of 80%, giving it the best score among the five websites tested, while the KG website received the lowest score of 66%. The PEA website also achieved a high score of 79%. The latest MAUVE++ tool showed that the BGB website achieved the highest accessibility score at 96%, while the PEA website scored 68%. In turn, KG reached 90% and BKW and BM achieved 74% and 70%, respectively.

4.3. Expert analysis

The third part of the experiment involved an expert analysis based on a checklist of 14 questions. The results of this analysis for each question are presented in figure 5.

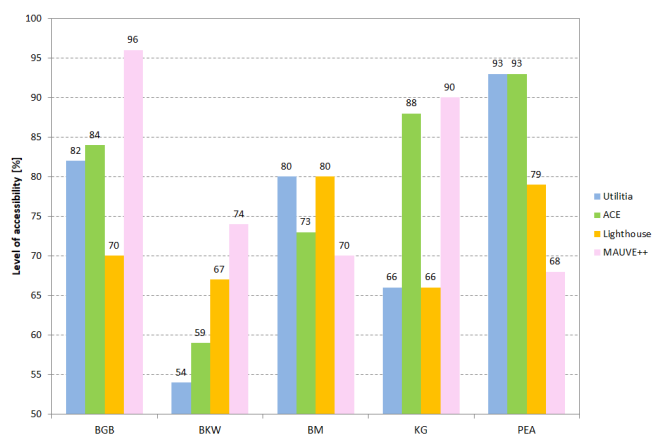


Fig. 4. The level of accessibility of virtual churches determined by selected automatic tools

Figure 6 shows the percentage of websites that met the criterion. Most services (80%), including BGB, BKW, KG and PEA, received positive ratings for their intuitive interface and ease of navigation. Only the BM web service was rated lower in this category, which means that its navigation was not fully intuitive. In terms of layout consistency and aesthetics, the services performed very well. Each of the websites (BGB, BKW, BM, KG, and PEA) received a positive rating in this category, which means that the webpages were well organized and visually friendly. All websites offered mobile versions that automatically adjusted to different screen sizes, which was also highly rated.

In terms of loading times, all webservices performed very well, none of them exhibiting any delays that could negatively affect the user experience. Accessibility tools for people with disabilities, such as audio transcription, subtitles, and keyboard control, were only present in the BKW, KG, and PEA web pages, and this increased their rating. The BGB and BM websites did not have these features, which resulted in their lower final score. As for interactive elements, such as buttons and links, all websites received positive ratings for their visibility and ease of identification. Considering the quality of built-in search tools, only BGB, BKW and BM offered search engines with high relevance and ease of use. The KG and PEA web pages did not have this functionality, which lowered their ratings. Experts assessed that all web services, regardless of users' previous experience, were easy to learn. Navigation was rated as intuitive in 80% of the websites, and only BM had problems in this

Virtual walks	BGB	BKW	BM	KG	PEA
1. Intuitiveness of the interface	1	1	1	1	1
2. Consistency of the page layout	1	1	1	1	1
3. Mobile version	1	1	1	1	1
4. Page loading time	1	1	1	1	1
5. Smooth operation of the virtual tour	1	1	1	1	1
6. Accessibility tools	1	1	1	1	1
7. Visibility of interactive elements	1	1	1	1	1
8. Functionality of the search engine	1	1	1	1	1
9. Ease of learning to use	1	1	1	1	1
10. Interactivity of the virtual tour	1	1	1	1	1
11. Image quality during the tour	1	1	1	1	1
12. Additional information (e.g. narrations)	1	1	1	1	1
13. Navigation during the tour	1	1	1	1	1
14. Additional materials (quizzes, games)	1	1	1	1	1

Fig. 5. Map with results for fourteen criteria for evaluating virtual church services

category. Only two virtual web services (BM and KG) offered additional information in the form of church descriptions or audio narration. The BGB, BKW, and PEA did not have these features. The KG was the only one that offered additional interactive and engaging elements, such as quizzes and educational games, that differentiated it from the others.

In conclusion, none of the websites analysed met all the criteria highlighted in the expert checklist (figure 7). Although there were some accessibility and usability issues that need to be fixed, the virtual tour websites studied were ultimately highly rated.

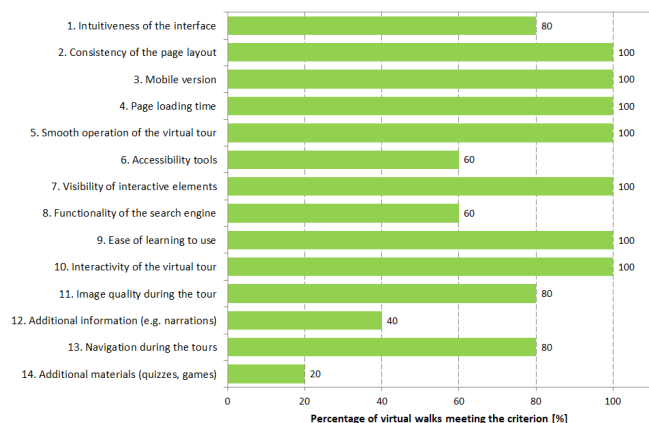


Fig. 6. Degree of achievement of each criterion for all virtual church tours

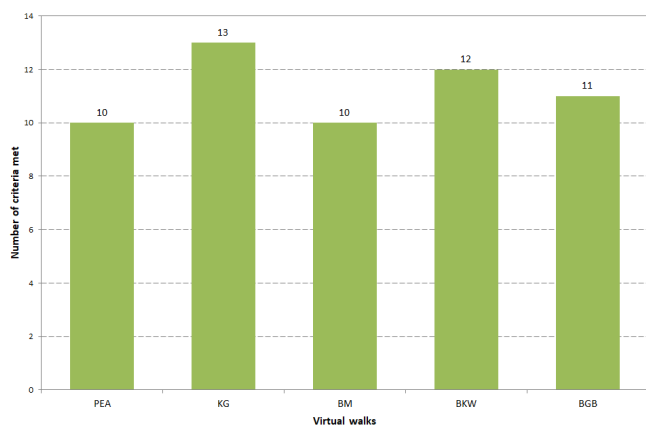


Fig. 7. Number of criteria met for each virtual church

5. Conclusions

The use of three different research methods allowed for a more complete assessment of the websites tested. A survey completed by users provided subjective feedback that reflects the actual experience of real users when using virtual tours. Analysis using automated tools verified the technical compliance of such websites with the WCAG guidelines, identifying accessibility issues for certain user groups, i.e., the elderly or people with disabilities. In turn, expert analysis provided a qualitative assessment of the intuitiveness of the interfaces and the functional solutions implemented.

The results obtained from the three studies complemented each other. For example, navigation difficulties reported by users were confirmed by experts, and color contrast issues detected in automated tests were reflected in the low readability ratings expressed by respondents.

In the first stage, users evaluated the virtual tours based on a checklist consisting of five groups of questions about

the interface, the entire screen, terminology, learning-to-use, and system features. The PEA walk received the highest overall score (89.09%), indicating a high level of quality and user satisfaction. The lowest score was given to the BM tour (74.13%), which may indicate difficulties in use and limited accessibility. The other walks (BGB, BKW, KG) achieved relatively high quality scores ranging from 85 to 88%. It should be emphasised that the highest results were in the categories of "learning-to-use" and "system features", the averages of which exceeded 90%. The lowest scores were for aspects of "interface", indicating the need to improve the intuitiveness and layout of this element.

The second stage included analysis using automated tools such as Utilitia, ACE, Lighthouse, and MAUVE++. These tools allowed us to assess the accessibility of the walks in terms of WCAG compliance. The two virtual walks PEA (83.25%) and BGB (83%) received the highest average scores, indicating relatively high compliance with the guidelines. The BKW walk scored the lowest at 63.50%, while the other two walks, BM and KG, achieved scores of 75.75% and 77.50%, respectively. The most common problems detected were the absence of alternative texts, insufficient color contrast, and missing header hierarchy. Due to the fact that the results obtained using various automated tools differ significantly, the analysis performed should be supported by expert manual verification of accessibility.

The third stage of the research included an expert analysis, which was based on a checklist of 14 questions on usability, accessibility, and broadly understood interface quality. In this analysis, the BKW and KG walks received the highest scores, which stood out in particular for their intuitive navigation, well-designed interface structure, and additional functionalities such as audio narrations. The BM tour received the lowest score, which was mainly due to limited intuitive navigation and a lack of tools that support accessibility, while the PEA walk had shortcomings with regard to the search engine and the quality of the displayed image.

The results of the study confirm both hypotheses. Hypothesis 1, which assumes that websites offering virtual walks do not fully meet accessibility requirements, is reflected in the results of automatic tools and expert analysis, which pointed to problems such as the lack of alternative texts or insufficient color contrast. In turn, the hypothesis, suggesting varying levels of usability depending on technology and implementation was confirmed by differences in user ratings and expert evaluations, which showed an advantage for some virtual walks. Such an example is the BM walk, which was made with the most advanced 3D scanning technology and achieved the worst results, through a nonintuitive interface, difficult controls, and the way the content is displayed caused by the technology used.

The use of three different research methods made it possible to obtain a comprehensive assessment of the studied virtual churches, identify their strengths and weaknesses, and formulate conclusions. Looking at the results obtained – the better and the worse – it can be concluded that there is still area for improvement in virtual churches in terms of accessibility and usability.

The completed research has some limitations. They were based only on 5 virtual tours of selected churches. Currently, there are many such web services, and new ones are constantly being created. An important element of research conducted was accessibility, and therefore, the group of respondents should be expanded to include people with disabilities. To make the results more objective, it would be good to use the eye-tracking technique, which provides quantitative measurement data that refer to objective psychophysical and neuropsychological processes and oculomotor responses to stimuli received from the environment.

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M.Sc. Michał Mitura

e-mail: michal.mitura1@pollub.edu.pl

Graduate of the Lublin University of Technology in the field of Computer Science. His research interests include web development and, in particular, JavaScript-based technologies.

<https://orcid.org/0009-0005-2370-9017>

Ph.D. Mariusz Dzieńkowski

e-mail: m.dzienkowski@pollub.pl

Assistant professor in the Computer Science Department at the Faculty of Electrical Engineering and Computer Science at Lublin University of Technology. His scientific interests include human-computer interaction, eye tracking applications and web application development.

<https://orcid.org/0000-0002-1932-297X>

