Benchmarking between the DQL Index and the Web Application Accessibility Index using Automatic Test Tools

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Abstract
Every day, humanity is witnessing digital transformation, which involves implementing digital technologies to transform business processes and services from non-digital to digital. The success of this transformation is measured by the Digital Quality of Life (DQL) Index, and VPN service provider Surfshark publishes the study results. As Index DQL grows, so does the number of users because digital accessibility is becoming more popular daily. The increase in digital information, the continuous development of IT, and the transition of life online require software to be accessible to people with disabilities. There is a question about the correlation between software availability level and Index DQL. This research is dedicated to the solution to this issue. Ten European countries were randomly selected, and automated testing of the accessibility of government websites was carried out using the following tools: Tenon, Wave, and SiteImprove. The term Web application accessibility index was defined. For the first time, an analysis of the correspondence between Index DQL indicators and the web application accessibility index was carried out. Even though the EU countries and their partner states are constantly working to improve conditions for people with disabilities, a high DQL Index does not indicate a high level of accessibility of state websites, which was confirmed by the study.

Keywords
Digital quality of life, accessibility testing, automatic test tools.

1. Introduction

Every day, humanity is witnessing digital transformation, which involves implementing digital technologies to transform business processes and services from non-digital to digital. This includes, among other things, moving data to the cloud, using technology devices and tools for communication and collaboration, and automating processes. Digital transformation makes life easier and helps quickly solve many problems. It is intended to improve the quality of digital life that spending on digital transformation technologies and services is constantly increasing worldwide, as evidenced by the Statista website (see Fig. 1) [[1]–4].

Digital transformation means implementing digital technologies to transform business processes and services from non-digital to digital. Digital services are benefiting in almost every field of activity. The availability of the Internet and digital spaces has led to the emergence of e-commerce services and various options for working on the Internet. This includes, among other things, moving data to the cloud, using technological devices and tools for communication and collaboration, and automating processes [5]. High digital quality of life facilitates and accelerates the resolution of several issues by citizens of one or another country. The Digital Quality of Life (DQL) Index is calculated by looking at the impact of five core pillars:

1. Internet Affordability: This pillar determines how long an individual has to work to afford the internet, specifically the cheapest mobile and broadband internet.

2. Internal Quality: this pillar determines the stability and speed of the internet for both mobile data and broadband. It also considers the growth of speed and strength.
3. Electronic Infrastructure: this pillar measures how developed a country's e-infrastructure is. Better infrastructure results in smooth online experiences such as banking, shopping, entertainment, education, etc.
4. Electronic Security is a measure of a nation's cyber security and includes various strategies the country has developed to decrease cyber-crimes and protect the privacy of its people.
5. Electronic Government is the pillar that reviews the advancements of the government in the digital sector. This results in lesser corruption, better transparency for the public, and efficient public services [[5]].

According to a study published by the VPN service provider Surfshark, there is a corresponding distribution of DQL among the countries of the world and Europe (see Fig. 2).

The Digital Quality of Life 2021 index analyses 110 countries worldwide in terms of five core pillars: internet affordability, internet quality, e-infrastructure, e-security, and e-government. These pillars consist of 14 indicators that are interrelated and work together to measure the overall digital quality of life [[5]]. Countries were evaluated based on index scores with the best possible value equal to one. Denmark is the best at 0.83, followed by South Korea (0.76), Finland (0.76), Israel (0.74), the United States of America (0.74), and Singapore (0.72). Ukraine ranks only 47th in this ranking.
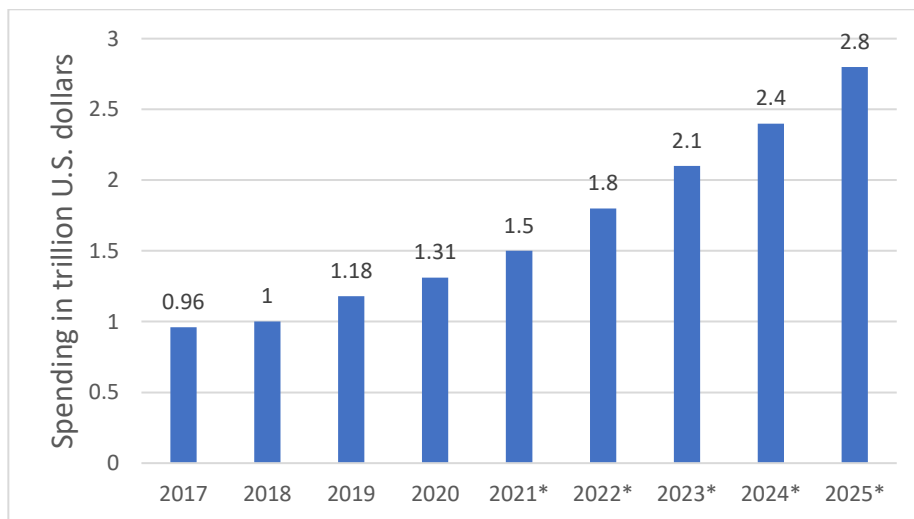

Figure 1: Spending on digital transformation technologies and services worldwide from 2017 to 2025 in trillion U.S. dollars
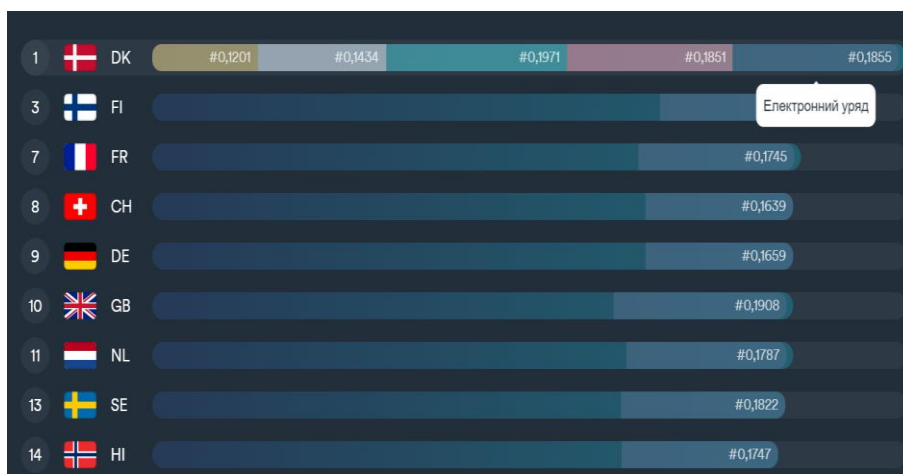

Figure 2: Digital quality of life index in Europe for 2021

With the growth of DQL, the number of users of government Internet applications is growing, among which a particular share is occupied by people with special needs, whose number is constantly increasing. Such applications have several requirements. Note that to solve these issues, on October 26, 2016, the EU Parliament and the Council of the European Union passed the EU Web Accessibility Directive, and on June 7th, 2019, the European Union formally adopted the European Accessibility Act. The Directive aims to create a more standardized and harmonized framework around the accessibility of websites and mobile applications of public sector bodies [6]. The Directive complements the European Accessibility Act, which covers a wide range of products and services also in the private sector. Further European legislation supports people with disabilities in other areas, including electronic communications, audio-visual media services, eBooks, eCommerce, and ICT equipment [7]. Following the specified directive, the following terms were established: on September 23, 2019, all new public sector websites and apps were required to conform to the directive; by September 23, 2020, all new and existing public websites must conform to the directive; by June 23, 2021, all new and existing mobile apps must conform to the directive [6]. Thus, the question arises about the relationship between the DQL index and the availability of web applications of state importance.

2. Related Works

The issue of software availability is quite broad and multifaceted. It has worried several scientists but is still not revealed and not completed. Scientists: M. Goldberg [8], M. Campoverde-Molina [9], K. Ordonez [10], G. E. Constain [11], J.S. Silva [12], K. Brown [[13]3], M. Sashnova [[14]], etc. Nielsen Norman Group [[15]], which is a world leader in user experience research, needs special attention. For the past few years, their research has focused on website accessibility.

Several scientists are working on the issue of inclusive software: A. Savidis [[16]], J. Ohene-Dzhan [[17]], I. Niculescu [[18]], K.M. Martinez [[19]], V. Boronos [20] and others. A small number of publications are devoted to studying the digital quality of life.

The analysis of publications in this direction showed that:

1. There are no clear and unambiguous definitions of such concepts as "disability," "accessibility," "person with disabilities," or "person with special needs," which has some ambiguity in research and needs clarification and agreement at the global level.
2. There are no clear definitions and concepts of such terms as "accessibility web design," "inclusive software," or "universal web design."
3. To ensure a high level of content accessibility for people with disabilities, WAI (Web Accessibility Initiative), within the framework of the World Wide Web Consortium (W3C), developed the Web Content Accessibility Guidelines (WCAG) standard. Version WCAG 2.1 was adopted as the standard of the European Union EN 301 549 [21]. The recommendations for ensuring the accessibility of web content are the most universal, and many countries have adapted these requirements to their laws.
4. There are many programs for automated web application accessibility testing. In the vast majority, they do not check all WCAG 2.1 requirements, so there is a need for several automatic testing tools.
5. No scientific publications highlight the issue of the DQL Index, its factors, the relationship between the DQL Index, the availability of web applications, etc.

Therefore, the study of scientific and practical literature, publications, and publications on the Internet proved that the issue of the relationship between the level of accessibility of software and the Digital Quality of Life index needs thorough research and analysis, and there is also a need to improve accessibility testing standards. Thus, this article aims to analyze accessibility standards, research existing automated web application accessibility testing tools, and correlate test results with the Digital Quality of Life index.

3. Index Correspondence Research

By Directive (EU) 2016/2102 Of The European Parliament And Of The Council of 26 October 2016 on the accessibility of the websites and mobile applications of public sector bodies [22], it is the applications of public sector bodies that require accessibility.

The standard contains a number of recommendations on what needs to be done to make the web-content accessible to people with

disabilities. Recommendations are grouped according to four principles: perception, manageability, comprehensibility and reliability. These recommendations are called success criteria, and according to them, the application can receive one of three levels: A, AA or AAA. Accessibility testing at the appropriate level is performed by automated systems and testers who check whether the content of the site meets the relevant criteria and assess the usability of the platform [[23]3].

The Accessibility Conformance Testing (ACT) Rules Format 1.0 defines a format for writing accessibility test rules. These test rules can be used for developing automated testing tools and manual testing methodologies. It provides a common format that enables any party involved in accessibility testing to document and share their testing procedures in a robust and understandable manner. This enables transparency and harmonization of testing methods, including methods implemented by accessibility test tools [[24]].

There is a range of tools for automated testing, including Google ADT, Tenon, aXe, Wave, SiteImprove, and others. We have chosen the following tools for automated testing of the availability of government websites: Tenon, Wave, and SiteImprove. This choice is due to the GDS accessibility team's audit of the most used accessibility tools [[25]].

Technology is constantly changing, so the web application's user experience will vary depending on the technical capabilities of browsers and devices. Not all browsers display web pages the same way. There are often noticeable differences in how browsers handle technologies like CSS, HTML, and JavaScript. Because, according to statistics provided on the Statcounter GlobalStats website, the browser market share in Europe was distributed as follows: Chrome 59.29%, Safari 19.97%, Edge 5.86%, Firefox 5.83%, Samsung Internet 3.62%, Opera 3.02% [[26]]. That is why, within the framework of this study, testing the availability of web applications of state importance was carried out in Google Chrome.

We have chosen 10 European countries randomly to ensure the sample's representativeness: Denmark, Switzerland, United Kingdom of Great Britain and Northern Ireland, Luxembourg, Poland, Italy, Greece, Ukraine, Albania, Montenegro [27–36].

Table 1 contains the results of testing the accessibility of Government website home pages with the appropriate automated testing tools.

Testing of Siteimprove Browser Extensions was carried out according to the following criteria:
- Error. Occurrences of an issue that have been automatically determined to be in contravention of the Web Content Accessibility Guidelines (WCAG) 2.
- Warning. Occurrences of an issue that have been automatically determined to be in contravention of best practices under the Web Content Accessibility Guidelines (WCAG) 2.
- Review. Issues that cannot be checked automatically but requires a manual inspection to determine if each item lives up to the success criteria.

Testing of WAVE Browser Extensions was carried out according to the following criteria:
- Error. Occurrences of an issue which have been automatically determined to be in contravention of the Web Content Accessibility Guidelines (WCAG) 2.
- Contrast Errors. Text is present that has a contrast ratio less than 4.5:1, or large text (larger than 18 point or 14 point bold) has a contrast ratio less than 3:1. WCAG requires that page elements have both foreground AND background colors defined (or inherited) that provide sufficient contrast. When text is presented over a background image, the text must have a background color defined (typically in CSS) that provides adequate text contrast when the background image is disabled or unavailable. WAVE does not identify contrast issues in text with CSS transparency, gradients, or filters.
- Alerts. Occurrences of an issue that have been automatically determined to be in contravention of best practices under the Web Content Accessibility Guidelines (WCAG) 2.
- Structural Elements. The number of structural elements on the page, such as headings of different levels, ordered lists and unordered lists, navigation, etcetera.

Tenon testing was carried out according to the following criteria: Total Issues, Error Density.

Table 1
Test results according to the relevant criteria

№	Country	2021 Digital Quality of Life Index	Siteimprove Browser Extensions			WAVE Browser Extensions				Tenon	
			Errors	Warning	Review	Errors	Contrast Errors	Alerts	Structural Elements	Total Issues	Error Density
1	Denmark	1	14	3	20	11	2	7	56	2	7
2	Switzerland	8	16	8	23	19	16	114	139	10	21
3	Great Britain	10	5	4	23	0	1	2	40	2	3
4	Luxembourg	15	8	4	21	20	21	5	45	22	8
5	Poland	25	9	4	21	15	11	9	34	9	11
6	Italy	27	12	2	16	7	0	8	37	18	8
7	Greece	38	7	2	20	0	0	53	5	21	6
8	Ukraine	47	27	4	20	11	9	22	128	14	19
9	Albania	64	22	6	21	16	40	31	66	37	5
10	Montenegro	78	11	4	20	0	0	43	54	2	11

Fig. 3 shows an infographic of the research results compared to the DOL Index.

To determine the accessibility index of the website, we use the formula:

$$I = \frac{n \cdot E}{\sum_{i=1}^{n} k_i} \cdot 100\%, \qquad (1)$$

Where n is the number of evaluation criteria of the web application, E is the number of elements that have been checked, k is the number of errors for each criterion.

Fig. 4 shows an infographic that demonstrates the correspondence between the DQL Index and the accessibility index of the home pages of the Government website.

According to the results of this study, it can be concluded that there is no correspondence between these indices.
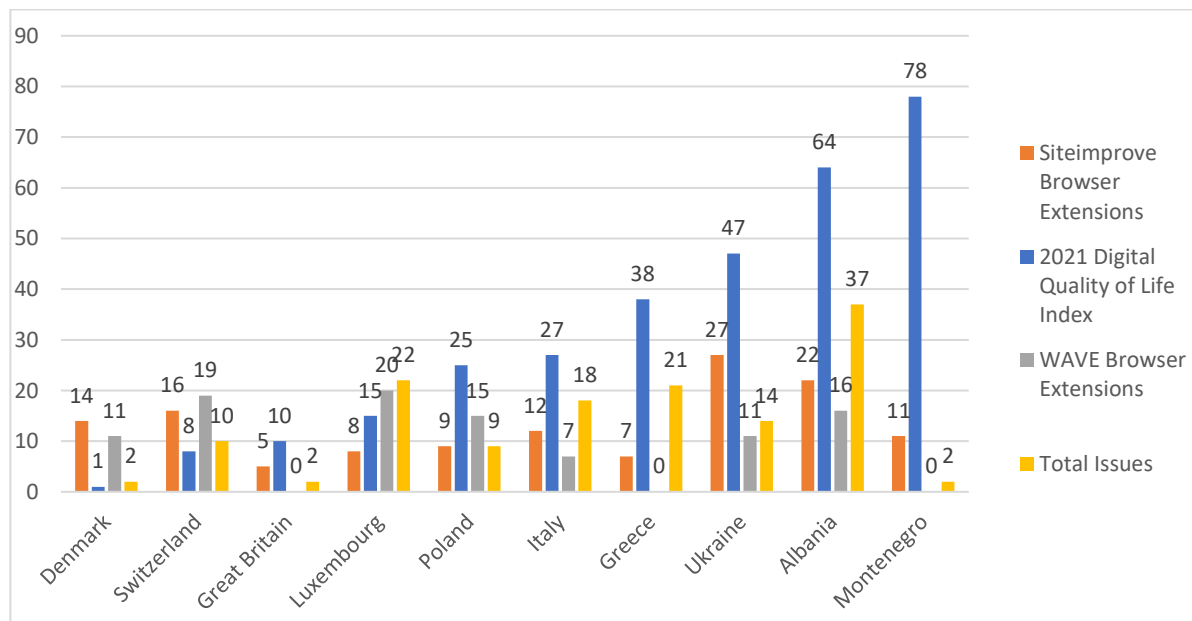

Figure 2. Correspondence diagram of the number of errors according to the relevant criteria and the DQL Index
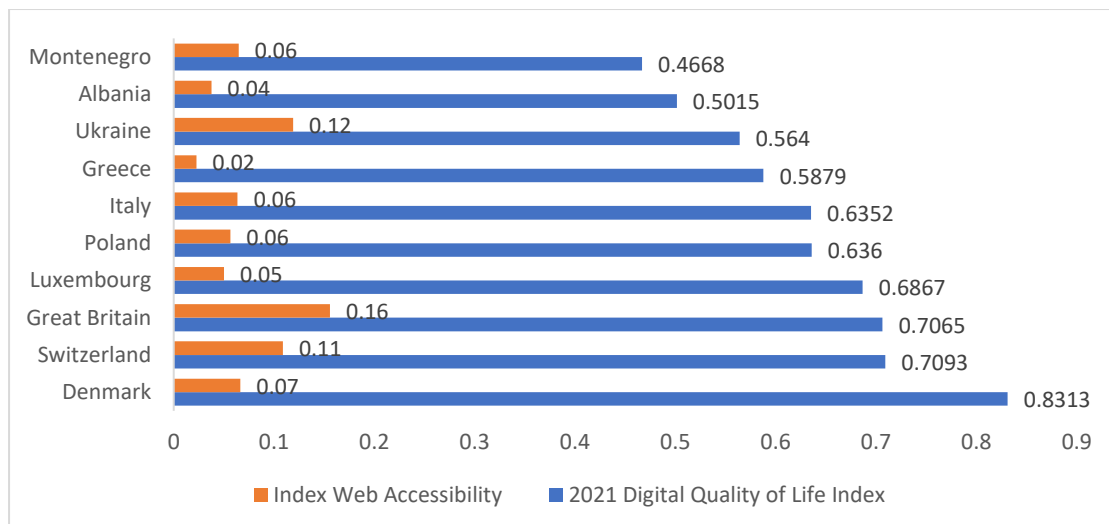
Figure 4. The correspondence between the DQL Index and the accessibility index of the home pages of the Government website.

4. Conclusion

The DQL index is calculated by analyzing the impact of five main components: Internet accessibility, Internet quality, e-infrastructure, e-security, and e-government. It does not consider the accessibility requirements of digital products, in particular web pages. It should be noted that EU countries and their partner states are constantly working to improve conditions for people with disabilities, but the DQL Index does not indicate a high level of accessibility of state websites. This is evidenced by the results of the conducted research. For the first time, an analysis of the correspondence between Index DQL indicators and the web application accessibility index was carried out. Even though the EU countries and their partner states are constantly working to improve conditions for people with disabilities, a high DQL Index does not indicate a high level of accessibility of state websites, which was confirmed by the study.

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