



# A Comprehensive User Experience Analysis of Cultural Heritage Progressive Web App Using A Hybrid UEQ-IPA Approach

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This study utilised a user-centred design (UCD) approach integrated into the Agile framework to develop Sarawak Cultural Heritage Progressive Web Apps (SCHPWA). The user experience (UX) of SCHPWA was evaluated using a combination of the User Experience Questionnaire (UEQ) and Importance-Performance Analysis (IPA) to measure six dimensions of UX. The evaluation involved 239 participants, comprising 184 females and 55 males. The results indicated that the SCHPWA scored above average in attractiveness, perspicuity, efficiency, and stimulation. However, the dimensions of novelty and dependability scored below average. Therefore, the attributes related to attractiveness, efficiency, stimulation, and perspicuity are grouped using IPA under Quadrant 2 (Possible Overkill), while novelty and dependability fall under Quadrant 3 (Low Priority). The study highlights the benefits of using a combination of UEQ and IPA for evaluating Progressive Web Applications (PWA). Furthermore, it suggests the potential to improve the UX of cultural heritage PWAs. These findings offer insights for designers and developers in optimising the UX of cultural heritage PWA.

**CCS CONCEPTS**•Human-centered computing~Ubiquitous and mobile computing~Empirical studies in ubiquitous and mobile computing •Information systems~Information systems applications~Collaborative and social computing systems and tools

**Additional Keywords and Phrases:** Cultural Heritage, Digitization, Progressive Web Apps, User Experience

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## 1. INTRODUCTION

Culture is an integral part of a person's identity and is intricately linked to their sense of belonging, background, and heritage. Cultural assets can be broadly classified into two categories: tangible and intangible. Intangible cultural heritage comprises practices, representations, expressions, knowledge, and know-how passed down from one generation to another within communities. These practices are continually evolving and transformed by communities based on the environment, history and interaction with nature [1]. In contrast, tangible heritage refers to physical artefacts such as sculptures, manuscripts, monuments, archaeological sites and shipwrecks. However, both tangible and intangible heritages are susceptible to extinction over time.

The advent of the internet has enabled the preservation of cultural heritage by converting analogue data into digital form. The concept of digital cultural heritage is based on the understanding that cultural heritage is fragile and vulnerable to destruction during times of war [2, 3, 4, 5] and disasters [6] or environmental pollution [7, 8]. Digitisation involves creating digital artefacts by converting pictorial, graphical, or textual inputs from their original physical attributes using electronic devices [9]. Digitisation is crucial in cases where cultural heritage sites have been destroyed or damaged, such as the destruction of the Temple of Baal, one of the oldest and most culturally significant pieces of architecture, by terrorism in 2015 [10].

Digitisation involves using electronic devices to convert physical items into digital forms. This includes selecting and preparing the analogue originals, creating metadata, and submitting the digital resources to the management system and depositories [9]. Cultural heritage digitisation aims to safeguard and preserve assets for the long term and make cultural content more widely accessible [11]. An information system collects hardware, people, and processes in gathering, processing, storing, and distributing data [12]. In recent years, digital libraries and archives have been largely replaced by information systems in terms of how information is presented and accessed [13, 14, 15].

Digital Library Systems (DLS) are specialised information systems that store, manage, and preserve digital content over time [16]. As more historical artefacts are increasingly digitised, DSL will facilitate easy access to this information, ensuring that digital content is preserved for future generations.

Web-based information systems significantly benefit cultural heritage stakeholders, the tourism industry, and the national heritage repository [17]. From the tourism perspective, an information system can make information more understandable and presentable, as well as retain and improve tourism quality of services provided by tourism providers. From a national heritage repository perspective, a digital information system can aid in managing heritage resources [15].

Digitalising cultural heritage is not new globally or in Malaysia [18, 19, 20, 21]. However, there is a lack of studies focusing on digitising cultural heritage in Smartphone applications, Web Apps, or Progressive Web Applications (PWA) in Malaysia. PWA is a term to describe applications that take advantage of accessing browsers offline, accessible across different devices, and provide the experience of a native app [22]. Hu and Zhu [23] have demonstrated that implementing PWA into cultural information systems can improve user experiences (UX), provide more modern application

features, and facilitate user-friendly data management. Their study supports the notion that web-based applications can help increase the intellectual and physical accessibility of cultural heritage.

Web-based applications have been criticised for their lack of security, inability to access device hardware and incomplete UX when users primarily perform actions or transactions on their mobile devices, whilst native mobile applications, on the other hand, have been praised for their dependability, independence from connectivity, and consistent UX [79]. However, native apps have high development costs, are platform-specific, and require more user data and storage. PWA offers several advantages, including dependability, speed, offline functionality, cross-platform availability and discoverability, and the ability to keep up-to-date knowledge upon refresh. Furthermore, PWAs can be added to users' home screens and launched like native apps while still offering the convenience of web applications. Therefore, PWA is the ideal solution for the current study due to the shortcomings of both native and web-based platforms. It provides the best of both worlds, offering a seamless UX with native-app features while also being accessible through the web.

Multiple studies have been conducted in Malaysia to digitise the country's cultural heritage, as evidenced by previous works [18, 19, 20, 21]. Ariffin's [18] study highlights the dearth of literature on digital local cultural content in mobile learning, especially in Local Cultural Studies, and underscores the need to bridge the gaps. The study concluded that it is crucial to establish awareness and strategies for sustainable local content development in Malaysia to encourage the utilisation of mobile devices for learning.

Malaysia takes pride in its diverse cultures and heritages, yet more efforts are necessary to preserve and promote them. For example, cultural treasures such as the intangible performing art of Mak Yong [21], a virtual tour of the tangible site of Kellie's Castle [19], and documenting the local knowledge and culture of Semai [20], Malaysia's indigenous people community, should be digitised. Similar studies on Sarawak's cultures have been conducted to achieve this objective [24, 25, 26, 27]. Sarawak is the largest and most diverse state located on the island of Borneo. It is home to more than 40 ethnic and sub-ethnic groups, each with a legacy of physical artefacts and intangible attributes passed down through generations. Sarawak has a population of around 2.81 million [74] (DOSM, 2020). Despite its rich heritage, a well-established and entirely digitised information system for Sarawak's cultural heritage has not been established. Previous studies [24, 25, 26, 27] have been insufficient in documenting and integrating the state's cultural assets. Digitising Sarawak's cultural heritage can benefit the tourism sector by promoting Malaysia's uniqueness in arts, culture, and heritage, advocating conservation and preserving this tangible and intangible heritage. For example, one ethnic minority in Sarawak is the Kelabit which mainly resides in the remote and rural areas of Borneo Highland. In 2020, British Museum showcased on its website the 137 artefacts gathered by Dr Monica Janowski, a social anthropologist who conducted comprehensive research on the Kelabit ethnicity [75]. Other digitisation effort studies conducted by various researchers, such as [24, 25, 26, 27], could provide more information on the Sarawak Cultural Heritage. Furthermore, the SCHPWA developed in this study can provide detailed information on Sarawak Cultural Heritage (interested readers can access this at <https://sarawak-dch.firebaseio.com/>).

Evaluation is a crucial aspect of cultural heritage, as it helps the researchers understand how visitors interact with cultural heritage objects, sites, and exhibitions. Several studies, such as [28, 29, 30, 31, 32, 33], have employed various evaluation methods, including observational studies using field notes, questionnaires, and interviews to evaluate UX in the cultural heritage domain.

However, evaluating a PWA in any domain may require a different approach due to its unique features, which combine web-based and native apps. For example, the unique features of PWA are its responsiveness, connectivity dependent, behaviour similar to the native app (native app-like), information always up to date (only when connected to the internet), security (the website require to run under HTTPS), discoverable, installable (similar to native apps), re-engageable using the service worker feature, easily shared using URL and progressive [80, 81, 82, 83, 84, 85, 86]. Therefore, some researchers, such as [34, 35, 36, 37, 38], have used different evaluation methods, including a questionnaire, qualitative, and a combination of pictograph (Self Assessment Manikin) and Communicability Evaluation methods to evaluate PWA UX. Questionnaires such as UEQ were used to evaluate the PWA (i.e. [34, 76, 77, 78]). However, to our knowledge, no study combined the UEQ and IPA to evaluate PWA, which this study aims to bridge.

Despite the growing interest in UX evaluation of digital technology and the adoption of various methods for evaluating UX in the cultural heritage domain, there is a lack of research addressing PWA evaluations in the cultural heritage domain. This study aims to bridge this gap and contribute to understanding UX. Furthermore, the lack of PWA adoption in the cultural heritage domain is also a motivating factor behind this study.

This study aims to address the following research questions:

- 1) What are the UX of the Sarawak Cultural Heritage Progressive Web Apps (SCHPWA) using UEQ?
- 2) What are the UX of the Sarawak Cultural Heritage Progressive Web Apps (SCHPWA) using a combination of UEQ and IPA?

The structure of this document is as follows: Firstly, the following section presents a comprehensive review of prior studies related to cultural heritage, UX, and digitisation. It will highlight the gaps in the existing literature and provide the rationale for the current study. This will be followed by the conceptual framework section, which presents a novel approach that integrates the UEQ and IPA to evaluate the cultural heritage PWAs. Next, the research methodology section outlines the methods and procedures for collecting and analysing data, while the results and discussions section will provide an in-depth analysis of the findings, including their implications for the research questions. Finally, the conclusions section will summarise the key findings and implications and recommend future research.

## **2. LITERATURE REVIEW**

### **2.1 Digital Cultural Heritage and Digitisation**

Implementing a web-based digital information system began in 2009 with MOSAICA [14], which aimed to preserve and present cultural heritage information. MOSAICA facilitates semantic searches on

topics or cultural heritage keywords, presents cultural heritage information through virtual walkthroughs and storytelling, and allows users to share and upload their information onto the site [14]. EUROPEANA is another popular web-based digital cultural heritage information system that has taken years of research and evaluation to serve as Europe's cultural heritage information repository [72]. In 2012, Purday discussed the technical challenges of heritage digitisation and provided an overview of EUROPEANA and the project's distribution and engagement plans [39]. Haslhofer and Isaac [40] extend EUROPEANA's research by studying the site's metadata and creating a Linked Open Data prototype, allowing single access to millions of digitised cultural objects in Europe.

Previous studies have been conducted on digitising cultural heritage and its effects on society, including research by [41, 42, 43, 44, 45]. Although these studies are primarily concerned with protecting the respective cultural materials from the dangers of technological advancement and rapid development [46], they paradoxically rely on technological support. Technology can benefit cultural heritage institutions such as galleries, libraries, archives, and museums by facilitating integrative practice [21]. Therefore, rather than viewing technological modernisation as the main threat to endangered cultural heritage, we should reconsider the value of technology in cultural conservation.

The Internet of Things (IoT) refers to interconnected computer devices automatically transferring data and information objects over a network. The digitisation of information allows for long-term information storage of data that can be backed up to cloud storage and physical hard drives. Jara et al. [47] have introduced the concept of a Smart Town that utilises IoT to preserve and revitalise historic towns. The Smart Town vision integrates the four key concepts: preservation, revitalisation, liveability, and sustainability, appreciating the past, living the present, and planning for the future. In addition to the concept of cultural heritage preservation, which was briefly discussed in the study above, Marshall [48] explores the potential of IoT in cultural heritage application. The system would allow for interconnectivity within cultural-space exhibits while providing visitors with more personalised interactions.

Researchers have been testing the application of IoT and their developed system in many existing museums, exhibitions, and cultural spaces, such as a sculpture exhibition in Naples [42], San Michele church in Venice [43], and Kasunan Surakarta Palace in Surakarta, Indonesia [45]. The IoT has been introduced into cultural heritage by developing technology and systems to transform cultural spaces and their presentation. Overall, IoT in cultural heritage can provide visitors with a more interactive and engaging experience while allowing for the preservation and revitalisation of historical sites. With ongoing research and development, the potential for integrating IoT into cultural heritage is vast and promising.

Traditional methods of preserving cultural heritage, such as storing them in private archives, old written documents, or less public settings, such as museums and galleries, limit the audience that can access them. Digitising these artefacts can open up a wealth of diverse heritages from various cultural backgrounds and ethnicities to anybody from any part of the world. For instance, the Liechtenstein National Museum in Germany has employed digitisation to cater to different subgroups of visitors, including children and youths, middle-aged adults, and elders aged 60 and above. As more elderly embrace technology and social media, digitisation offers an exciting way to engage them to visit and learn more about exhibitions. The use of digital cultural heritage has taken various forms, and

researchers and institutions continue to develop better and more technologically advanced methods of displaying digital data. In the case of the Liechtenstein National Museum, augmented reality (AR) and social media have been incorporated into their digital exhibition to encourage more people to visit the original collection, educate the general public, and serve as a marketing tool.

Studies have been conducted to promote accessibility in cultural heritage exhibitions using various forms of media such as text, images, videos, animation, and AR or virtual reality (VR). For example, Barak et al. [14] developed MOSAICA, an information repository for users to access cultural heritage resources. The project involves actively preserving and nurturing their heritage through storytelling, investigating cultural heritage resources, and exploring places and events using maps.

Recent studies have expanded the digital cultural heritage domain by implementing 3D models ([41], [49], [50]). By using 3D imaging, researchers can acquire, reconstruct, curate, manage, and preserve cultural assets such as the vulnerable wall structure and a damaged mural painting of St. Anne's church in Warsaw [49] or the cultural assets of Qatar [41]. Furthermore, Zakrajsek and Vodeb [50] developed a mobile app that provides descriptions, photos, and an interactive geographical map to promote heritage using 3D models. In conclusion, digitising cultural heritage presents a promising way to make heritage accessible to a wider audience. Incorporating advanced technologies such as AR, VR, and 3D models provides more interactive and engaging ways to preserve and promote cultural heritage. Such advancements serve as marketing tools for museums and galleries and encourage people to visit and learn more about cultural heritage.

## **2.2 Digital Cultural Heritage and UX**

More related software has been developed as research on digital information systems becomes more prominent in cultural heritage. However, the success of such software is not solely based on its functionality but also on its ability to encourage satisfaction. This has led to the emergence of UX research, which seeks to understand users' perceptions of a software's functionalities and experience. UX is described as a field that systematically designs and analyses users' holistic experiences, perceptions, and responses when interacting with technology [51]. However, despite the broad adaptation of UX in the industry, there is no unanimity on its scientific definition or theoretical framework [52].

Furthermore, in the digital library domain, researchers address how a user evaluation of digital libraries can help better understand users' needs [53]. The study noted a gap in qualitative and quantitative research, resulting in the obstruction to understanding UX. In the digital library domain, there are several research questions that researchers have to consider. The first research question is about the relationship between users' needs, expectations, and perceptions of the digital library. These aspects are interrelated, whereby users' needs affect their expectations toward the system and how they perceive the end product. Konstantakis et al. [54] analysed users' requirements while developing a roadmap that helped define their experience. The study also proposed methods for enhancing user modelling and describing user interaction between users and cultural products.

This domain's second central research question is, "What is the system's mode of interaction?" The primary purpose of an information system is to provide users with information, and the system must allow users to search, browse, and retrieve information. Van den Akker et al. [55] conducted a study

that provided a framework for evaluating online access to cultural heritage regarding Provision-Support and Information-Interpretation. How a heritage collection is presented can aid or hinder users' interpretation [55].

The most traditional mode of interaction between a user and a system is 'Search'. Search systems such as Google and Wikipedia have undoubtedly been highly successful. However, a 'search engine can only be useful if users know what they want. On the other hand, 'browse' allows users to explore the information presented and consider different paths that narrow their search scope.

A cultural heritage information system should support users by providing heritage information within the cultural heritage context. Therefore, an information system must provide access to the objects and allow interpretation. Furthermore, they must support end-users in searching and browsing the provided information, narratives, and cultural exhibitions. Moreover, information consumption has become one of the uniform main internet activities across all age groups, a common factor in satisfying users of the cultural heritage information system [56].

The digital cultural heritage domain is focused on several research questions, including user studies methods and measures for conducting UX evaluation. The third research question pertains to user studies methods, and there are various methods for conducting evaluation studies. For example, Shiri and Stobbs [57] conducted a community-driven user interface evaluation of the Inuit community digital library in northern Canada, utilising a three-phase user evaluation approach that included surveys, interviews, information audits, community workshops, and information tables. Using diverse data collection methods allowed the researchers to collect data on key features such as user engagement, search and browse, and interface features.

The fourth research question in this domain focuses on measures for conducting UX evaluation. Evaluation measures can be divided into objective and subjective methods for collecting quantitative and qualitative data [53]. Cultural heritage systems are commonly evaluated objectively due to their simplicity and efficiency. For example, Barak et al. [14] distributed questionnaires pre-use and post-use of the system, measuring disposition toward open-mindedness, usability, and learning outcome. Heo et al. [56] evaluated three scales used to measure cultural heritage portals and concluded that these scales complement one another in accessing the aspects that influence user satisfaction toward cultural heritage portals. Thus, measuring user satisfaction with cultural heritage digital portals using a single scale is insufficient as digital cultural heritage is a comprehensive information system.

A recent study has systematically evaluated a digital system called e-Dunhuang [58]. However, unlike previous studies, Reunanen, Díaz, and Horttana [59] conducted extensive subjective usability evaluations. They performed 6 test tasks, followed by semi-structured interviews to collect overall feedback impressions from test users regarding navigation and the content seen. They then conducted a lab test to cover the available functionality evenly. This 3-Dimensional evaluation method allowed researchers to identify physical environment issues, issues faced by evaluators and users, problems identified from the type of evaluation, and other miscellaneous issues. The researchers conducted nine user tasks with varying complexity levels through usability testing, followed by an in-depth interview. The qualitative analysis reveals why users felt certain about specific system criteria. This study motivated us to combine UEQ and IPA in measuring UX for PWA, which is novel for the PWA domain. From our knowledge, no previous studies have evaluated PWA using a combination of UEQ and IPA.

Regardless of the methods used in evaluating UX, the primary purpose of the usability evaluation remains the same: to provide developers with the tools they need to understand user needs better, improve overall product usability, and boost user satisfaction.

### 3. CONCEPTUAL FRAMEWORK

User Experience is critical to any digital product or service, including cultural heritage PWA. While several UX evaluation methods exist, they have limitations that can hinder their effectiveness in providing a comprehensive understanding of UX. To address these issues, this study applied a conceptual framework that combined the UEQ and IPA to evaluate the UX for cultural heritage PWAs. Based on our research, the combination of UEQ and IPA has not been used before in evaluating PWAs in any domain, significantly contributing to the cultural heritage domain. Furthermore, this framework is designed to provide a more comprehensive understanding of the UX of PWAs, considering the user's perception of importance and performance.

#### 3.1 User Experience Questionnaire (UEQ)

The user Experience Questionnaire (UEQ) is a reliable and efficient tool for measuring UX that provides quantitative evaluation results, facilitating fast and direct data processing [60]. Although initially designed as a part of a standard usability test, the UEQ is also appropriate for an online questionnaire, which participants are encouraged to complete quickly to ensure completion [61]. With 26 attributes measuring experience in attractiveness, efficiency, satisfaction, stimulation, and novelty, the UEQ offers researchers a general overview of UX when using the product. The UEQ has been employed in various studies with promising results. For example, a study assessing the UX of e-report applications revealed that, despite receiving high satisfaction scores, users experienced errors and failures in one of its features, indicating its effectiveness [60]. Moreover, the study also found a lack of clarity, affecting users' processing time. In another study, the UEQ was used to evaluate an online learning system, yielding positive impressions across six categories and helping identify areas for improvement [60].

The UEQ can be used independently or with other tools to evaluate the UX of products or services further. For instance, combining UEQ with cognitive walkthrough and heuristic evaluation can provide a more comprehensive evaluation of effectiveness, efficiency and user satisfaction and offer recommendations for improvement from experts [60]. In another study, the combination of UEQ with the System Usability Scale (SUS) evaluated the UX of an English learning interface, providing valuable insights into users' impressions of different interface designs [62].

Moreover, UEQ can gather in-depth perceptions and problems through the focus group discussion. For example, Izabal et al. [63] used UEQ and a focus group discussion to redesign a new interface, considering the major problems and negative perceptions generated by the focus group. As a result, the new design resulted in positive results in a new evaluation.

In conclusion, UEQ serves multiple purposes, including comparing products' levels of UX, testing UX, and identifying improvement areas. Furthermore, UEQ is a valuable tool for researchers assessing UX due to its efficiency and effectiveness. Hence, we integrated UEQ with IPA in this study.



### 3.2 Importance-Performance Analysis (IPA)

IPA is a technique that can determine whether a product or service performs well or poorly for its attributes [64]. This technique is low-cost and easily understood, providing insights into where to focus and identifying areas that consume too many resources [65]. In addition, the IPA results can be presented on a grid, as shown in Figure 1, which facilitates data interpretation and increases the usefulness of the techniques in determining the way forward. Although there are several interpretations of the IPA grid (i.e. [64], [73] from the original IPA developed by [65], we followed the interpretation of [66] and [71].

The grid consists of four quadrants, each representing different values. The first quadrant, Q1 (Keep Up the Good Work), contains attributes with excellent performance and extreme importance, requiring no further action. The attributes falling under Q2 (Possible Overkill) have lower importance but high performance, making development unnecessary and inefficient. Attributes under Q3 (Low Priority) also require no action, as users rated their importance and performance as low. Q4 (Concentrate Here), however, is of vital importance. Attributes that fall under this quadrant are essential but with low performance, thus requiring concentrated effort to offer further development. Q4 pr presents the highest potential for product improvement [66].

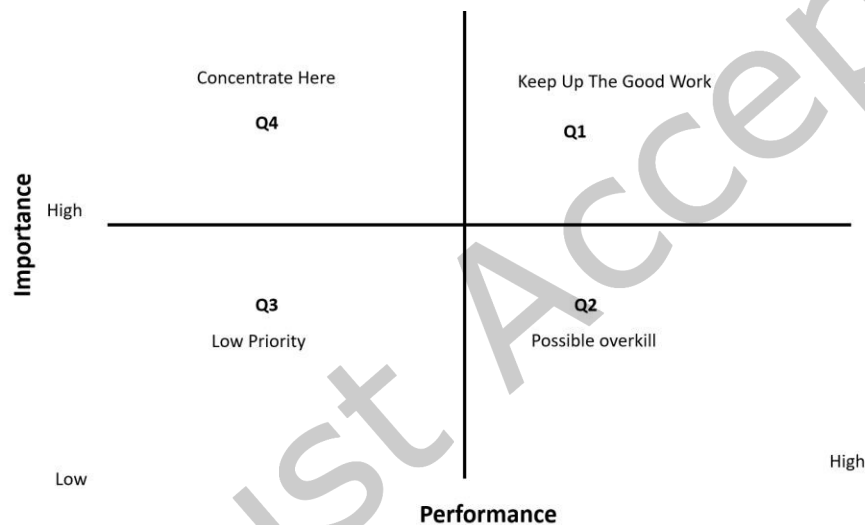


Figure 1: The Importance-Performance grid [65, 66, 71]

## 4. RESEARCH METHODOLOGY

### 4.1 Empirical Study

The empirical study was conducted to evaluate the UX of the SCHPWA. The SCHPWA is accessible via the following URL: <https://sarawak-dch.firebaseio.com/>

## 4.2 Participants

The study participants were randomly selected and included diverse respondents from students majoring in cognitive science, design, animation and others. They were chosen due to their background in Human-Computer Interaction (HCI) and web design. Two hundred thirty-seven responses were received, comprising 182 females and 55 males.

## 4.3 Apparatus and Materials

### 4.3.1 Progressive Web Apps.

The development of the SChPWA followed a systematic approach by using the Agile methodology with User-Centred Design (UCD) based on the framework proposed by Anwar et al. [67]. The study utilised a focus group of five participants purposively sampled to gather ideas and user requirements for the PWA's development. The focus group proposed various design ideas, allowing the researchers to create two types of user personas and a use case design for interaction with the PWA. The findings from this focus group study are detailed in Anuar and Othman [68]. Using this information, the researchers developed a low-fidelity prototype (wireframe) of the PWA, which was further refined into the SChPWA, as illustrated in Figures 2 (a) and 2 (b).

Figure 2 (a) shows the PWA in its native form, while Figure 2 (b) shows the PWA in its web app form. Users can access the PWA on their computer or mobile devices via the URL: <https://sarawak-dch.firebaseio.com/>. Users accessing the PWA through its native form can do so via the icon on their smartphone, while those using the web app can access the system through the URL.

Figures 3(a) and 3(b) depict the PWA used to measure UX in this study. To illustrate the PWA's features, we have shown the web app accessed on a computer in Figures 3(a) and 3(b). Upon opening the PWA, users are directed to the home screen (Figure 3(a)), which features a navigation button or panel on the left and the contents on the right. Users can browse through PWA's cultural heritage system or read information on different ethnicities. At this stage, users can also contribute to the cultural heritage by submitting pictures and relevant information by clicking the "contribute" button. They will then be directed to a new screen, as Figure 3(b) illustrates.

Sarawak boasts over 40 different ethnics and sub-ethnicities groups, each with its unique cultural heritage. However, the current Sarawak Cultural Heritage PWA only focuses on the cultural heritage of five main ethnic groups: Iban, Bidayuh, Malay, Melanau and Orang Ulu. Data was collected from social media platforms such as WhatsApp, Facebook, WeChat, Twitter and Instagram using ethnography or "wisdom of the crowd" to develop the initial Sarawak Cultural Heritage PWA databases. Experts at Majlis Adat Istiadat Sarawak validated the information collected to ensure accuracy. We successfully collected 387 pieces of data during this process, and after expert validation, we included 342 of them in the final version of the PWA. Our goal is to provide reliable and comprehensive information on the cultural heritage of Sarawak's diverse communities through this PWA.

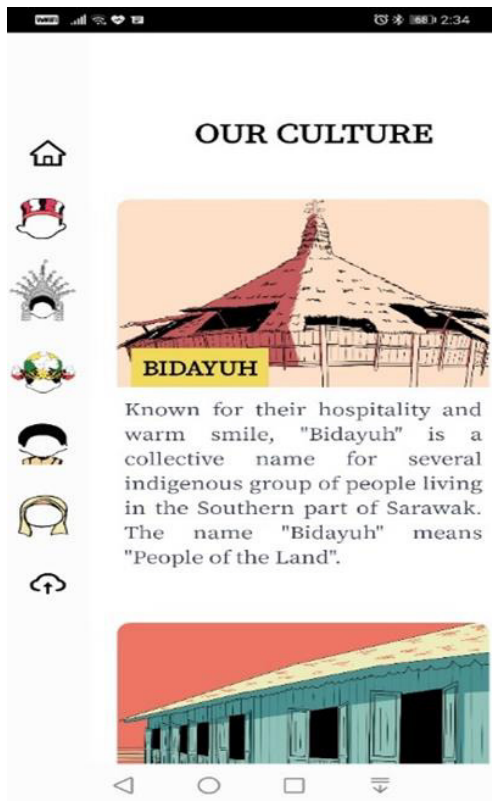


Figure 2 (a) Accessing the PWA like a native app

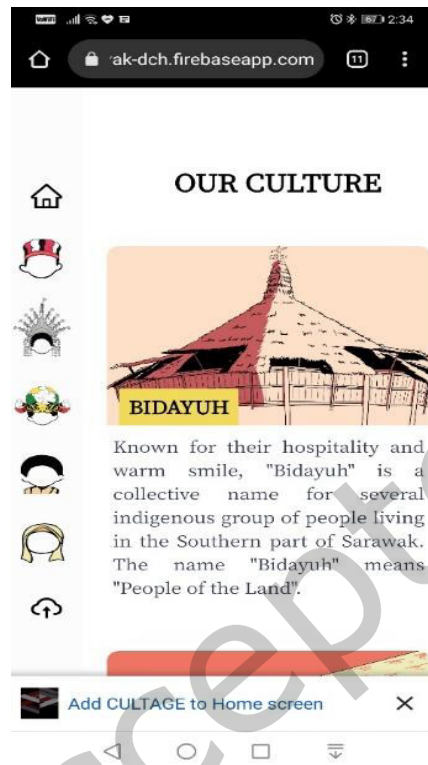


Figure 2 (b) Accessing the PWA as a web-apps

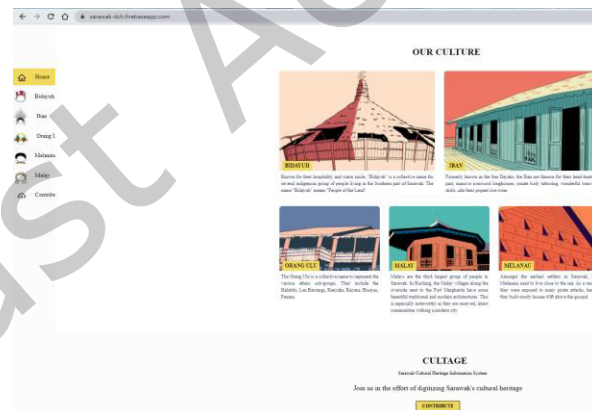


Figure 3 (a): home screen of Sarawak Cultural Heritage PWA (accessed using the URL)

#### 4.3.2 Research Instrument

In this study, we employed a comprehensive approach to evaluating the UX of the SCHPWA. To the best of our knowledge, Our study is the first to use a combination of two established methods, the User Experience Questionnaire (UEQ) and Importance Performance Analysis (IPA), to evaluate the UX of a

progressive web application in any domain. Previous studies such as [66] and [71] used this combination to evaluate Youtube, WhatsApp and Facebook. The UEQ, a reliable tool for assessing various aspects of UX, provides a quick and accurate measurement of key dimensions of UX, such as attractiveness, perspicuity, efficiency, dependability, stimulation, and novelty [69]. Additionally, we utilised the IPA method to identify areas for improvement and provide actionable recommendations based on the importance and performance of each dimension.

Figure 3(b): “Contribute” screen allows users to contribute to digitisation efforts.

#### 4.3.3 . Data collection procedure

The data collection procedure for this study involved the following steps:

**Participant recruitment:** We employed digital ethnography or netnography techniques to recruit participants for our study. By leveraging modern digital technologies such as email invitations and WhatsApp group blasts, we could tap into the crowd's wisdom and gather a diverse pool of respondents despite the challenges presented by the pandemic. In addition, participants were informed about the study's objectives, and the survey's estimated completion time of 15-20 minutes was communicated depending on the amount of time spent on the SCHPWA.

**Online Survey:** Upon recruitment, participants were directed to an online survey form with detailed instructions and an informed consent form. Participants were provided two options to access the PWA: via the web or native form. Each respondent was asked to (1) explore the PWA, (2) try the various functions of the SCHPWA, such as the “contribute functions”, which allow them to contribute to the digitisation effort and (3) to read any information about artefacts, traditional costumes, folklores and traditional ceremonies for minority ethnics of Sarawak, Borneo. Subsequently, the participants were asked to complete the UEQ questionnaire. The questionnaire consisted of a series of rating scales, and participants were asked to select the circle that best reflected their impression of the PWA, providing the most authentic impression. Participants were encouraged to make this decision spontaneously, without overthinking their response. Once the questionnaire was completed, each participant submitted their responses to the researcher.

#### 4.3.4 . Data Analysis

We conducted a descriptive statistical analysis to test the PWA UX, with the resulting data presented using graphical representations and average and percentage calculations for each aspect. Additionally, we analysed the UEQ data using the Importance-Performance Analysis (IPA) method to assess the performance of attributes with their importance in the system. This combined approach of UEQ and IPA is the first in the cultural heritage domain and has not been used before for PWA in any domain. These analyses provide valuable insights into understanding the effectiveness and significance of the PWA UX.

### 5. RESULT AND DISCUSSION

To evaluate the collected data, the average score from each aspect was attributed to the UEQ scales in the benchmark and used to measure the specified scale using the UEQ Data Analysis Tool. The benchmark results depict the relative quality of the SCHPWA in comparison to the benchmark presented in Table 1, and the benchmark graph is illustrated in Figure 4.

Table 1: Result Based on The Benchmark

Scale	Mean	Comparison to Benchmark
Attractiveness	1.43	Above Average
Perspicuity	1.28	Above Average
Efficiency	1.25	Above Average
Dependability	1.01	Below Average
Stimulation	1.27	Above Average
Novelty	0.55	Below Average

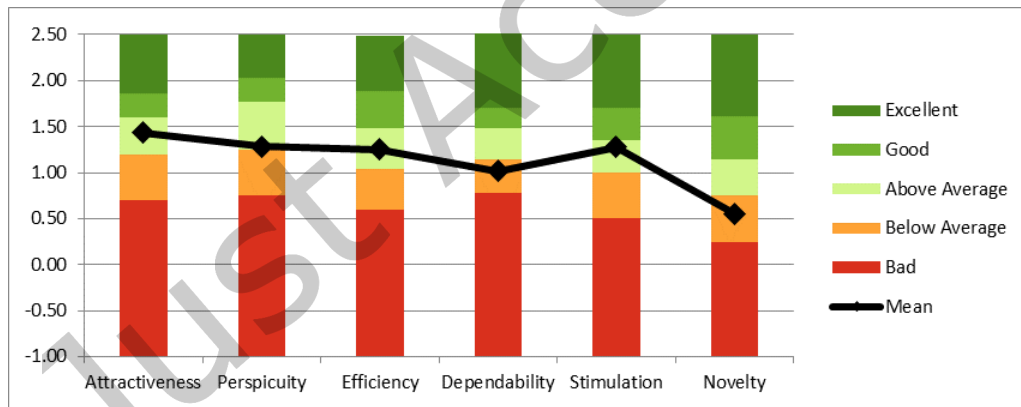


Figure 4. The relative UX quality of Sarawak Cultural Heritage PWA per scale is based on the mean value in the benchmark data set.

Our analysis revealed that the SCHPWA performed above average in attractiveness, perspicuity, efficiency, and stimulation while scoring below average for novelty and dependability. More specifically, our PWA was perceived to be more attractive, perspicuous, efficient, and stimulating than 25 per cent of the benchmark products, while it was less novel and dependable than 50 per cent of the benchmark products.

The UEQ analysis revealed that the item 'Convention vs Inventive' received the lowest mean score across all 26 attributes, as illustrated in Figure 5, contributing to the below-average score of the novelty category (0.55). This result could be because developing a progressive web app for Sarawak's cultural heritage might be new locally. Moreover, the system's execution was relatively conventional, and neither the functionality nor the PWA design was novel to the participants.

In contrast, the attractiveness quality received the highest mean score (1.43) compared to other qualities. Attractiveness is a pure valence quality that is determined by considering both pragmatic qualities (perspicuity, efficiency, and dependability) and hedonic qualities (stimulation and novelty) [69].

While hedonic value, hedonic usability, and hedonic quality terms are related concepts within the UX and product evaluation, specifically how users perceive and derive pleasure or satisfaction from using a product or system, they have distinct focuses and nuances. For example, hedonic usability relates to how pleasurable and enjoyable it is for users to interact with a product or system while accomplishing tasks. Hedonic usability involves various aspects such as ease of use, visual appeal, interactivity, and overall enjoyment while navigating and using the product. Hedonic usability recognises that user satisfaction is influenced by task efficiency and the overall experience of using the product. Also, hedonic usability focuses on whether a product is appealing, enjoyable, and original [70].

In this study, a product's hedonic value can be considered exciting or dull, depending on its mean value on a scale. Based on the mean value of our hedonic quality depicted in Table 2, we believe that the participant's impression of the PWA is dull instead of engaging.

The hedonic quality refers to a product's perceived excellence or desirability beyond its functional attributes and is concerned with how users assess its overall attractiveness, sensory appeal, and emotional value [88]. Hassenzahl [88] further discussed this in the UX model for users and designers.

Hedonic value refers to a user's emotional or psychological satisfaction from using a product or service. It encompasses the pleasure, enjoyment, or emotional resonance a user experiences during an interaction. Hedonic value is often associated with subjective perceptions, aesthetics, and emotional responses to a product. It goes beyond purely functional aspects and considers the product's ability to evoke positive emotions and enrich the user's experience. Diefenbach et al. posited that if the users appreciate the hedonic value of a product or system, they will invest more time with the product or a system [87].

Table 3 presents the confidence level for six components of UEQ, providing additional insights into the data's reliability and validity. Overall these findings suggest that while our PWA performed well in some aspects, there is room for improvement in novelty and stimulation to increase user engagement and satisfaction.

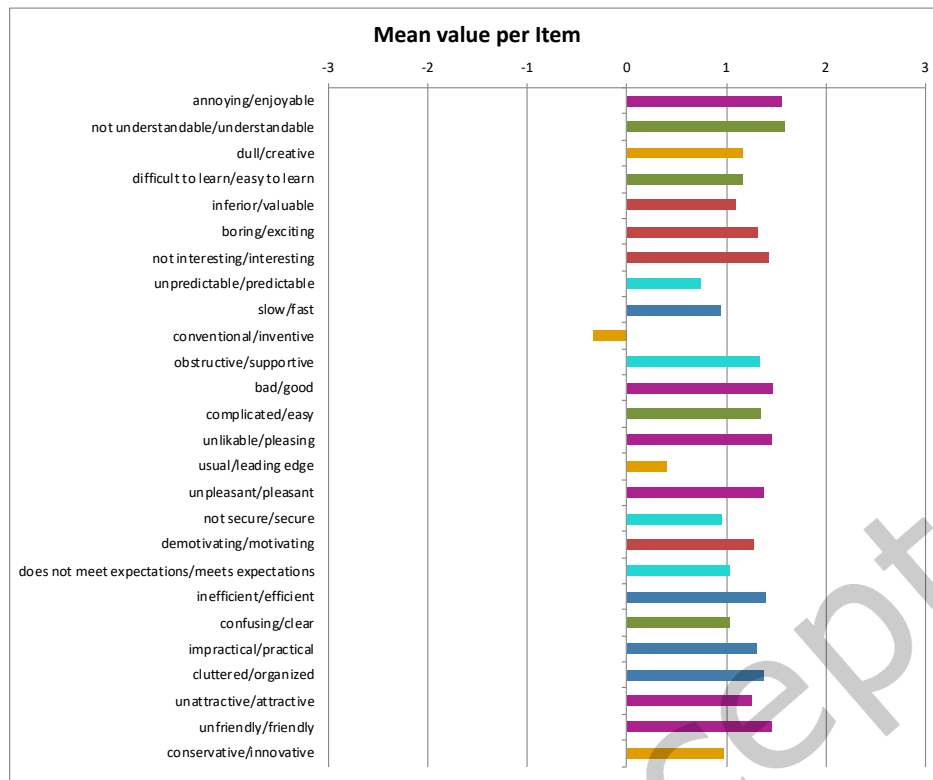


Figure 5: Mean value for all 26 UEQ attributes

Table 2. Mean Value For Pragmatic Hedonic Quality

Pragmatic and Hedonic Quality	Mean
Attractiveness	1.43
Pragmatic Quality	1.18
Hedonic Quality	0.91

Table 3. Confidence Level For Six Components Of UEQ

Scale	Confidence Interval (p=.05) per scale					
	Mean	Std. Dev	N	Confidence	Confidence Interval	
Attractiveness	1.430	1.137	237	0.145	1.286	1.575
Perspicuity	1.285	1.289	237	0.164	1.121	1.449
Efficiency	1.251	1.121	237	0.143	1.108	1.394
Dependability	1.014	0.985	237	0.125	0.888	1.139
Stimulation	1.274	1.100	237	0.140	1.134	1.414
Novelty	0.555	0.934	237	0.119	0.436	0.674

We then plotted the results of our IPA in a distribution chart, as shown in Figure 6. We follow [66] and [71] to plot the chart by having (1) based on the coordinate origin (dotted line) and (2) based on the coordinate origin in the mean values of all scales (solid lines). These methods are critical for interpreting the scales and forming corresponding quadrants. Table 5 shows the corresponding quadrant based on these two methods.

Table 4. PWA Mean Value In Terms of Performance (UEQ) And Importance

Scale	UEQ			Importance		
	Mean	Std. Dev	Confidence	Mean	Std Dev	Confidence
Attractiveness	1.430	1.137	0.145	0.33	1.19	0.15
Perspicuity	1.285	1.289	0.164	0.17	1.04	0.13
Efficiency	1.251	1.121	0.143	0.46	0.80	0.10
Dependability	1.014	0.985	0.125	0.40	0.93	0.12
Stimulation	1.274	1.100	0.140	0.40	1.41	0.18
Novelty	0.555	0.934	0.119	0.33	1.24	0.16

Confidence Interval (p=.05) per scale

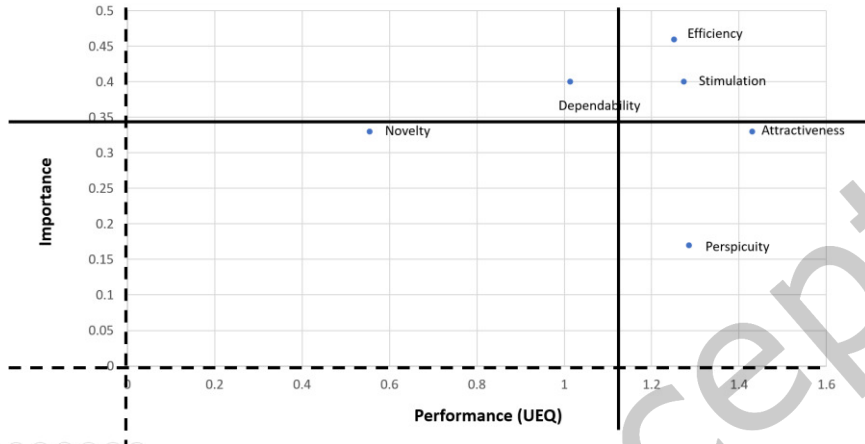


Figure 6. Results of the IPA for Sarawak Cultural Heritage PWA

Table 5: Scale Distribution to IPA Quadrant for SCHPWA based on [66, 71].

Scale	Scale Centre (0,0)	Scale Centre Average
Attractiveness	Q1: Keep Up The Good Work	Q2: Possible Overkill
Perspicuity	Q1: Keep Up The Good Work	Q2 Possible Overkill
Efficiency	Q1: Keep Up The Good Work	Q1: Keep Up The Good Work
Dependability	Q1: Keep Up The Good Work	Q4: Concentrate Here
Stimulation	Q1: Keep Up The Good Work	Q1: Keep Up The Good Work
Novelty	Q1: Keep Up The Good Work	Q3: Low Priority

Our analysis shows that attractiveness and perspicuity fall under quadrant 2 (Possible Overkill). These attributes received relatively low ratings from users regarding their importance compared to performance, which indicates that they are adequately developed. Users' expectations were met, and further development of these attributes would be inefficient. On the other hand, novelty attributes belong to quadrant 3 (Low Priority). The values of these attributes are well-balanced, but they are rated relatively low in terms of importance and requirements.

Consequently, no further action is necessary. The efficiency fall under Q4: concentrate here, whilst efficiency and stimulation fall under Q1: Keep Up The Good Work. Both values for the performance of



Attractiveness and Novelty are closely approaching the line, which could change the Quadrant values. However, these observation is beyond our scope of analysis.

Our study supports the previous study by demonstrating that signifying both axes with mean of performance and importance better represents the options for action regarding the UEQ [71]. Furthermore, this approach can provide valuable insights into UX, allowing developers and researchers to develop a more impactful and user-centric digital experience within the cultural heritage domain.

Several practical implications of this approach should be considered when adapting this approach in the cultural heritage domain due to the availability of digital tools and platforms. For example, researchers should consider different attributes suitable for the cultural heritage domain, such as engagement, emotions, interactivity, educational value, accessibility, and cultural sensitivity. Cultural heritage is inherently diverse, and its application is often developed for users from various cultural backgrounds. The UEQ can help identify the perceptions of users from various cultures. IPA can help developers prioritise the attribute that resonates with such culture while optimising the applications for the global audience.

Moreover, cultural heritage applications often seek to engage users in immersive and educational experiences. The UEQ can identify users' engagement, emotional connection and satisfaction, leading to a meaningful UX. IPA can help developers identify attributes that can lead to engagement and learning outcomes, which subsequently help the developers refine its contents and interactions. The usability and accessibility can lead to a better UX by providing users with easy-to-navigate, interact and understand applications. The UEQ can identify usability issues or challenges to access, whilst IPA can help prioritise improvements based on UX.

## 6. CONCLUSION

The UEQ is a valuable tool for researchers to quickly and efficiently measure the UX of a product. This powerful method utilises simple data collection techniques to measure various product versions, enabling researchers to obtain a high level of the product's position in the market by comparing the results to established benchmarks. However, like any quick evaluation method, the UEQ has its limitations, as it only provides general information about the product's strengths and weaknesses without offering specific solutions to address those weaknesses.

We applied the UEQ to evaluate the SCHPWA and found that it scored above average on the UEQ scale. However, upon further analysis of the individual attributes, we identified that the novelty and dependability attributes received the lowest scores, falling below the average. Therefore, we utilised the IPA to determine whether these attributes underperformed compared to their actual importance.

The IPA facilitates a powerful tool that facilitates data interpretation and enhances the usefulness of UEQ results. Using the IPA grid, we identified the attributes that required improvements based on their rated performance and importance. Our analysis revealed that attractiveness and perspicuity are grouped under Quadrant 2 (Possible Overkill), while Novelty fall under Quadrant 3 (Low Priority). Although these two attributes rated below average in performance, their importance differed, and dependability was viewed as more important. Although their values differed, the analysis shows that

these attributes require no further action. The findings also show that efficiency and stimulation fell under Q1, which is Keep Up The Good Work and requires no further action.

Our study employed a combination of two powerful methods, the UEQ, and the IPA, to evaluate UX for PWA due to the uniqueness of PWA features. This combination has not been previously available in the literature for PWA. While we acknowledge that there is always room for improvement in any product, including ours, the SCHPWA performed well across all UX attributes in this study. Overall, the UEQ and IPA offer a powerful approach to evaluating and improving a product's UX, providing valuable insights that can help guide future development efforts.

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