

Better Addressing Diverse Accessibility Issues in Emerging Apps: A Case Study using COVID-19 Apps

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ABSTRACT

The COVID-19 pandemic resulted in introducing a large number of “emerging apps” to the mobile app market. These apps were developed and deployed quickly to address the urgency of the situation. This gave us an indication that the cycle of having new emerging apps will likely reoccur in every upcoming emergency in the future e.g. for advice and guidance during bush fires, floods, other pandemics, etc. We carried out an in-depth analysis of user reviews and version history release notes for 30 COVID-19 apps that were developed in a great hurry in 2020. We identified many diverse accessibility issues that exist, not just related to conventional challenged end-user accessibility issues, but including the ability to register, access, download, and use from different app stores in different countries and for different end-users. From this large-scale analysis, we developed a new advisory tool for software developers of emerging apps to avoid many of the wide accessibility issues presented in these COVID-19 apps. A user evaluation of our prototype tool with 13 real-world app developers indicates it will assist developers to address many of these issues prior to initial emerging app deployment.

KEYWORDS

Emerging Apps, COVID-19 Apps, Accessibility, Mobile Apps, User Reviews, Version History, Analysis, Evaluation, Recommendations, Guidelines

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1 INTRODUCTION

Emergencies, pandemics and crises occur frequently all around the world [10, 28, 35]. For example, every year many countries face a considerable number of bushfires in the summer session, which results in significant life and property losses [11, 26, 34, 44]. The Black Summer bushfire season of 2019-2020 in Australia was marked by abnormally severe and destructive bushfires across the country [15]. A total of 18.6 million hectares of land was destroyed by the flames, as well as 2,779 dwellings and 34 people died, including 9 firefighters [15]. Losses from the Australian bushfires in 2019/2020 cost over A\$103 billion, including A\$1.866 billion in insurance claims [15]. Many issues occurred with the app developed to assist the public emerged during the emergency [16, 31]. The COVID-19 global pandemic has resulted – to date – of nearly 360 million people being infected with the SARS-CoV-2 virus, and sadly nearly six million have lost their life [45]. The global COVID-19 pandemic has changed the way we live across the world especially when it comes to repetitive lockdowns[9]. People have been advised to follow government, experts, and health authorities’ advice [1, 33]. According to [39], mobile tracing apps can play a critical part in ending the global pandemic when 60% of the public downloading and using COVID-19 contact tracing apps. Even lower app usage percentages may help in the fight against the virus and slow its spread and propagation, according to another study [32].

In [19], the authors stated that several issues occur and may prevent users from downloading or using these emerging apps even if they were willing to use them, such as accessibility, stability, or privacy problems. Emerging apps such as COVID-19 should be accessible by everyone in society regardless of their age, gender, language, culture, etc [43]. Emerging apps such as COVID-19 contact tracing apps are developed, designed, and tested in a short time span compared to other types of apps [19]. They are required to be rolled out quickly to users due to an emergency or pandemic which leads to be more prone to accessibility issues [29]. This causes many issues as they are supposed to be used by various types of users in society and they should be developed in a specific way.

In this paper we define **emerging apps** to be those developed in the middle of an emergency situation, and while usually highly funded due to their rapid design and roll-out have many accessibility issues [30]. Moreover, we have a wider definition for **accessibility issues** than issues faced by disabled users. We consider accessibility issues to be those that may affect or prevent any type of users from downloading, logging into or using these emerging apps. This results in them not being used or downloaded by a sufficiently high

number of people in the community [47]. Since these emerging apps aim to save lives, they need to be accessible by everyone in society. To the best of our knowledge, there are no sufficient guidelines or frameworks to help app developers build and design such accessible emerging apps targeted to emergency situations. We conducted a case study to analyse the main issues and problems manifested in 30 COVID-19 apps rolled out in 2020. We identify the main issues that prevented users from downloading and using these apps. From our detailed analysis of their app reviews and version history release notes, we designed, prototyped and evaluated a new tool to provide emerging app developers guided, concrete design advice to address many common accessibility issues. Our tool guidelines will help app developers to develop more accessible emerging apps in the future, which will lead to higher adoption, resulting in saving both money and lives. The key contributions of this work include:

- We carried out both automated and manual analysis of nearly 220,000 user reviews of common COVID-19 contact tracing apps to identify accessibility issues faced by users. We identified significant accessibility issues that prevented users from downloading or using these apps;
- We carried out a detailed analysis of the version history release notes of common COVID-19 apps. We identified the accessibility issues that were fixed by the developers of these apps and those that were not;
- We developed a new tool, the Emerging Apps Accessibility Evaluator and Recommender (EAAER). EAAER prompts developers for a range of characteristics of their planned emerging app, and uses their input/answers to generate evidence-based recommendations to ensure their apps are accessible by all types of users; and
- We carried out a developer evaluation of EAAER and received feedback from 13 real-world app developers, indicating EAAER's promise in supporting more accessible emerging app development.

2 MOTIVATION

Emerging mobile apps can be beneficial to decreasing economic loss and saving lives during emergencies, pandemics, and crises [12, 17, 37, 38]. Emergencies can happen quickly, such as bushfires in the summer months and floods in winter with localised support and guidance to impacted communities [10, 35]. Some are unexpected such as the COVID-19 pandemic and require major societal responses [8, 10]. Since emerging apps must be rolled out quickly to people in the event of an emergency or pandemic, they are most likely to be developed, designed, and tested quickly compared to other types of apps [19]. A recent example of such "emerging apps" are COVID-19 contact tracing apps. When the COVID-19 pandemic first broke out, medical experts and researchers had great hopes for digital contact tracing to help in ending the global pandemic and reducing the spread of the virus [32, 39]. These hopes were supposed to be achieved by using mobile contact tracing apps to record and promptly alert contacts when a user reports being infected with the virus [32, 39].

Governments around the world have highly funded the development of COVID-19 apps [30, 47]. Despite this and the ongoing

instructions and encouragement from governments and health experts to download and use them, as secondary waves of COVID-19 spread, these apps played a smaller role than initially anticipated [6]. One reason is that many of these apps had significant privacy and accessibility issues that prevented users from using them or led them to uninstall these apps [4, 19, 24].

By analysing user reviews for many COVID-19 apps, we can observe several accessibility issues that developers were not aware of while developing these apps. Some of these accessibility issues were repetitive across different apps and led users to be unable to use these apps and, in some cases, uninstall them, leading to lower adoption rates. An analysis of the version history notes of many COVID-19 apps shows that some developers were able to address some of these accessibility issues in time. Figure 1 shows parts of the users' reviews showing some of the accessibility issues that users submitted in their reviews, and a few parts of the version history for the same app showing that developers fixed them. Our motivation was to investigate and understand the relation between users' reviews and app version history for COVID-19 apps.



Figure 1: Accessibility issues later fixed in COVID-19 apps

No work has yet been done to understand the main accessibility issues that prevent users from downloading or using such emerging apps. We wanted to understand the relationship between the accessibility issues stated in the reviews and the app's version history notes. This will allow us to develop guidelines and a recommendation tool for developers of emerging apps to enhance accessibility, resulting in higher adoption rates when they release these apps. Public health officials, specialists, and software engineers will significantly benefit from understanding this relationship since it will help them enhance app design, methodologies, and accessibility. Following that, they will develop app updates to address these issues raised in the feedback from users. This could potentially save millions of dollars and save lives in an emergency or pandemic, and will increase the download and adoption rates of emerging apps such as COVID-19 mobile tracing apps. Thus we wanted to answer the following two key research questions:

RQ1 – What are the most common accessibility issues in emerging apps as evidenced in users' reviews and apps' version history?

RQ2 – How can we provide guidance to app developers to design and build more accessible emerging apps?

To answer these RQs, as a topical case study we analysed user reviews for commonly used COVID-19 mobile apps in both Google Play and App Store. We then review how developers updated their COVID-19 apps to fix these accessibility issues based on an analysis of version history. We developed a set of guidelines and a recommendation tool for developers of emerging apps to reduce and possibly prevent accessibility issues.

3 METHOD

To fully understand the range of key accessibility issues raised by the users of COVID-19 apps, we carried out two types of analysis. First, we extracted, translated, and did a large scale automated classification of 225,708 user reviews for 30 different COVID-19 apps on both Google Play and App Store [2, 14]. Followed by, a manual analysis of 9075 user reviews for these apps. Second, we did a manual analysis of each app's version history, updated app descriptions, and information submitted by the developers as shown in Figure 2.

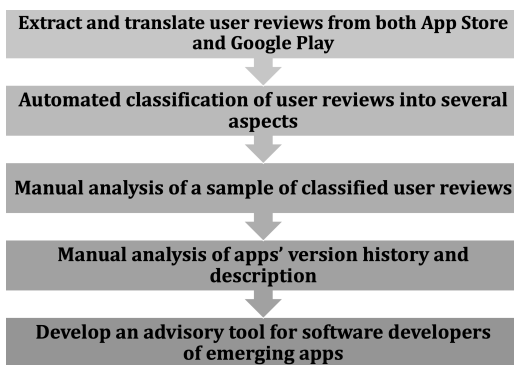


Figure 2: Our Methodology

3.1 Dataset

Aiming to ensure that the reviews are representative of the general population around the world, we extracted and translated the app reviews for 30 different COVID-19 apps on both Google Play and the App Store. This procedure resulted in extracting and translating 225,708 user reviews. We filtered those reviews into some aspects based on some keywords which resulted in having 21,594 user reviews, then manually analysed 9075 user reviews for these apps. We chose a range of COVID-19 tracing apps around the world. We also chose Apple and Android versions for comparative analysis. For our manual analysis of app version history notes and app descriptions, we manually analysed the version history logs for the same apps to understand what accessibility issues the developers managed to fix and which were not. Moreover, we manually analysed the description and app details submitted by the developers on both stores as shown in Table 1.

3.2 RQ1 – What are the most common accessibility issues in emerging apps as evidenced in users' reviews and apps' version history?

To understand the key accessibility issues that are faced by users of COVID-19 mobile apps, a set of questions was created about these apps. These question will assist us in comprehending what prevents users from downloading or using COVID-19 mobile apps. This includes what kind of problems that lead users to uninstall these apps and why.

What are the main compatibility issues that prevent users from installing and using COVID-19 apps? COVID-19 apps should be accessible by all types of users, regardless of what phone models they use or what firmware version they have. We wanted to know if COVID-19 apps could be downloaded and installed by different users, having different firmware and phone models. Another critical point in understanding the accessibility issues of an app. If users can not download the app for any reason, then there are serious accessibility issues.

How app developers are handling privacy concerns that users have in COVID-19 apps? We wanted to understand how COVID-19 app developers allow users to have the opportunity to understand precisely how their app is working, what algorithms it uses, and how it handles their users' data, and whether it collects this personal data or not.

What are the main issues that prevented users from using COVID-19 apps while signing up? Emerging mobile apps should be used by everyone in society. If some users are not able to sign up for these apps for any reason, then there are major accessibility issues.

Are COVID-19 apps accessible by all types of users in the society? Everyone in the community should be able to download and use emerging COVID-19 apps regardless of their age, nationality or language. If any of those users could not sign up to use these apps for any reason, then there are major accessibility issues.

Do COVID-19 apps developers interact with users? During an emergency, crisis or pandemic, everyone in the community should be able to feel heard and have the opportunity to provide their feedback for developers of emerging apps. This will help reduce misconceptions and myths and increase awareness among people about the importance of using these emerging apps. This awareness will result in having higher adoption rates for these apps.

3.3 RQ2 – How can we provide guidance to App developers to design and build more accessible emerging apps?

Since emerging apps are likely to be developed rapidly and have more limited testing, or at least rushed testing, compared to other types of apps, they are more prone to accessibility issues. This causes many problems as they are supposed to be used by all members of society, regardless of their age, language, culture and physical health. Based on the analysis we have done in our first research question, several repetitive accessibility issues are reported in both user reviews and developer update notes. Some of these issues were

Table 1: COVID-19 apps, country, number of reviews extracted, classified and analysed

Location	Name	iOS Reviews	Android Reviews	Total Extracted Reviews	Manually Analysed Reviews
Australia	COVIDSafe	3401	7328	10724	950
Austria	Stopp Corona	313	1434	1747	130
Bahrain	BeAware	69	1155	1224	90
Bulgaria	VirusSafe	51	494	545	50
Canada	COVID Alert	785	835	1620	70
Czech	eRouska	81	1107	1188	110
Denmark	Smittestopp	94	395	489	40
Fiji	CareFiji	8	138	146	20
France	StopCovid	830	4685	5515	500
Germany	Corona-Warn-App	9396	26694	36090	980
Gibraltar	Beat Covid Gibraltar	6	39	45	10
Hungary	VirusRadar	0	284	284	20
Iceland	Rakning C-19	49	79	128	10
India	Aarogya Setu	3923	58894	62817	850
Israel	HaMagen	295	668	963	90
Italy	Immuni	3163	11983	15146	850
Japan	COCOA	2103	39	2142	230
Kuwait	Shlonik	92	495	587	80
Malaysia	MyTrace	39	392	431	40
Mexico	CovidRadar	28	67	95	70
New Zealand	NZ COVID Tracer	392	1885	2277	180
Philippines	StaySafe	118	775	893	85
Poland	ProteGO	127	1084	1211	130
Qatar	Ehteraz	664	9583	10247	1110
Saudi Arabia	Tawakkalna	456	15132	15588	800
Singapore	Trace Together	854	2469	3323	270
Switzerland	SwissCovid	484	1153	1637	185
Thailand	MorChana	43	308	351	35
Turkey	Hayat Eve Şiğar	5482	40834	46316	900
UK	NHS COVID-19 App	628	1311	1939	190
Total	30 Apps	33974	191734	225708	9075

fixed by the developers of these apps, and some were not. To help developers we designed EAAER – Emerging Apps Accessibility Evaluator and Recommender tool – which asks app developers some guided questions and gives them instant evaluation and recommendations that might help them reduce or prevent common emerging app accessibility issues. We evaluated EAAER with a range of real-world app developers to get their feedback on its approach and accessibility questions and guidance.

4 RESULTS

4.1 RQ1 – What are the most common accessibility issues in emerging apps as evidenced in users’ reviews and apps’ version history?

We extracted and translated 225,708 user reviews for 30 COVID-19 apps, then classified these reviews based on used keywords and a large phrase dataset, chosen based on manually analysing over 23,000 user reviews. Afterwards, we went manually through each of the 9075 user reviews for these apps one by one. We conducted a manual analysis of the app versions’ history, descriptions, and other data provided by the respective developers on the App Store and Google Play, respectively. Table 2 summarises some of our findings. In the following sub-sections, we discuss the key accessibility issues found in these COVID-19 apps.

4.1.1 What are the main compatibility issues that prevent users from installing and using COVID-19 apps?

iOS and Android version support: Despite the fact that different governments, health authorities and medical experts are encouraging everyone in the community to download and use COVID-19 apps, some people were not able to do that since they do not own relatively new smartphones. Many users mentioned in their reviews, across different COVID-19 apps, that they could not download or install these apps since they do not support their iOS or Android version. For example, everyone living in Qatar must use the Qatari COVID-19 app since the app is mandatory for everyone, however, this app is not supporting any iOS lower than 13.1. This issue has massively affected elderly people and low socio-economic workers in particular who do not own relatively new phones. A few examples of user reviews raising compatibility issues affecting accessibility of COVID-19 apps are shown in Figure 3.

Many COVID-19 app developers released updates to enhance their apps’ compatibility. Lowering the supported versions of operating systems with their apps allows more people to download and use them. In some apps, these compatibility updates were released after a few weeks, while in others, it took several months. Surprisingly, some COVID-19 apps are still only supporting high end operating systems even now. For example, the Danish COVID-19 app (Smittestopp) was released on 17 Jun 2020. On 27 Jan 2021, the developers of the Smittestopp app released an update to enhance accessibility by supporting old iPhones. This update allowed iPhone 5s, 6, or 6+ holders to install the app, as shown in Figure 4. On the other hand, the Italian COVID-19 app (Immuni) only supports iOS 13.6 or later for Apple devices and version 7.0 and up for Android devices. The developers of the Immuni app did not fix this issue

Table 2: OS version, age, privacy, location, language, store, interaction and fix data for COVID-19 apps

App name	iOS version	Android version	Age rating	Privacy rating (iOS)	Request for location permissions (Android)	Number of languages	International Store	Does developer interact with users in reviews?	Release Detailed Update Notes?
COVIDSafe	10.0 or later	5.0 and up	4+	Data Linked to You	Yes	10	Yes	No	Yes
Stopp Corona	13.5 or later	6.0 and up	17+	Data Not Collected	No	2	Yes	Yes	No
BeAware Bahrain	11.0 or later	4.4 and up	4+	Data Not Collected	Yes	6	Yes	Yes	No
Virusafe	10.0 or later	5.0 and up	12+	No Details Provided	Yes	4	No	No	No
COVID Alert	12.5 or later	6.0 and up	4+	Data Not Linked to You	No	2	Yes	Yes	Yes
eRouska	13.5 or later	6.0 and up	4+	Data Not Linked to You	No	3	Yes	Yes	Yes
Smittestopp	12.5 or later	6.0 and up	4+	Data Not Linked to You	No	2	Yes	Yes	Yes
careFIJI	10.0 or later	5.1 and up	4+	Data Linked to You	Yes	1	Yes	Yes	No
StopCovid	11.4 or later	5.0 and up	4+	Data Not Linked to You	Yes	7	Yes	No	No
Corona-Warn-App	12.5 or later	6.0 and up	12+	Data Not Linked to You	No	6	No	Yes	Yes
Beat COVID Gibraltar	12.0 or later	6.0 and up	4+	Data Not Linked to You	No	1	Yes	No	No
Rakning C-19	12.5 or later	5.0 and up	4+	Data Not Linked to You	No	2	Yes	No	Yes
Aarogya Setu	10.3 or later	5.0 and up	4+	No Details Provided	Yes	2	Yes	No	No
HaMagen	10.0 or later	5.0 and up	4+	Data Not Collected	Yes	2	Yes	Yes	Yes
Immuni	13.6 or later	7.0 and up	12+	Data Not Collected	No	5	Yes	No	No
COCOA	13.5 or later	6.0 and up	4+	Data Not Linked to You	No	3	Yes	No	Yes
Shlonik	11.0 or later	7.0 and up	4+	Data Linked to You	Yes	5	Yes	No	No
CovidRadar.mx	8.0 or later	5.0 and up	17+	No Details Provided	Yes	1	Yes	No	No
NZ COVID Tracer	10.0 or later	6.0 and up	4+	Data Linked to You	No	1	Yes	No	Yes
StaySafe PH	13.5 or later	6.0 and up	12+	Data Not Collected	No	1	No	Yes	No
ProteGO Safe	12.1 or later	5.0 and up	17+	Data Not Collected	No	4	Yes	Yes	Yes
Ehteraz	13.1 or later	6.0 and up	12+	Data Linked to You	Yes	2	Yes	No	No
Tawakkalna	10.0 or later	6.0 and up	4+	Data Linked to You	Yes	7	Yes	No	Yes
Trace Together	10.0 or later	5.1 and up	4+	Data Linked to You	Yes	6	Yes	Yes	Yes
SwissCovid	12.0 or later	6.0 and up	12+	Data Not Collected	No	6	Yes	No	Yes
MorChana	9.0 or later	5.0 and up	4+	Data Not Linked to You	Yes	2	Yes	No	No
Hayat Eve Sigar	11.0 or later	5.0 and up	4+	Data Not Collected	Yes	2	Yes	No	Yes
NHS COVID-19 UK	13.5 or later	6.0 and up	12+	Data Not Linked to You	No	11	Yes	No	Yes
Overall Stats	11.x+: 14% 12.x+: 25% 13.x+: 25%	5.x+: 43% 6.x+: 46% 7.x+: 3%	4+: 64% 12+: 25% 17+: 11%	Data Linked: 25% Data Not Linked: 36% Data Not Collected: 29%	Yes: 53% No: 47%	2<=: 53% 2+: 47%	Yes: 89% No: 11%	Yes: 39% No: 61%	Yes: 53% No: 47%

“ COVIDSafe - Australia: “Such a massive \$2 million fail. I can’t even get it to register on a 2 year old phone, 1★”

Ehteraz - Qatar: “Many workers have challenges with their respective employers if they don’t have the apps installed on their phones. And if they it will affect their salary payment and absenteeism at work. This is not encouraging so the developer of this apps should make it available for iPhone 6 users. Some people may not have the money to buy the latest phone. As is a government directives to download this apps, let there be a way to help those that buy newer phones, 1★”

Smittestopp Denmark: “Seems like a nice app but I have 2 parents who have only iOS 12.4.7 and you can therefore not download it to their iPhones. Hope it will be solved because not everyone needs to switch to new models, 3★” ”

Figure 3: Version compatibility issue review examples

“ Smittestopp - Denmark: “Thank you for using Smittestopp. This version introduces support for using the app on older iPhones. This means that it is now possible to install the app if you have an iPhone 5s, 6 or 6+.”

Corona-Warn-App - Germany: “The app now supports smartphones on iOS version 12.5”

NZ COVID Tracer - New Zealand: “We’ve added support for devices running iOS 11, made some improvements to accessibility, and fixed some bugs”

SwissCovid - Switzerland: “Support for iOS 12 (iPhone 5s, iPhone 6, iPhone 6 Plus)”

Beat COVID - Gibraltar: “Minor updates and support for iOS 12.5”

COVID Alert - Canada: “Updated the app to work on older iPhones: 5s, 6 and 6 Plus with iOS 12.5” ”

Figure 4: Accessibility issue fix examples

until the time we were writing the paper, preventing many people in Italy from using the app. A few excerpts of version history fixing compatibility issues affecting accessibility of COVID-19 apps are shown in Figure 4.

App availability on the international vs local store: Some COVID-19 apps are only accessible by users using a local country app store and they are not available in the international store. This reduces the app’s accessibility to visitors, students, and immigrants from other countries as they will not be able to download the app unless they change their app store to the local one. Australian

non-residents, such as visitors and students, who were not setting their mobile app stores to Australia, were not able to download the COVIDSafe app. This issue was reported in many user reviews and was later fixed by the developers of the app as shown in Figure 5.

People residing in Bulgaria, Germany, and the Philippines who do not use the local app store will not be able to download the local COVID-19 apps. Virusafe, Corona-Warn-App, and StaySafe PH do not exist in the international store, as shown in Figure 6. According to our user review analysis, this issue mainly affects visitors, students, and non-residents as they are setting their app



Figure 5: Region and locale app fix & review examples

stores to other countries. Several users have reported this issue; however, as of the time of writing, the problem still exists in some COVID-19 apps.

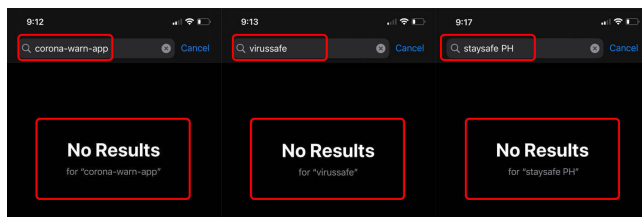


Figure 6: Store (un)availability examples

4.1.2 How do app developers handle user privacy concerns?

Our analysed user reviews showed that many mobile users have privacy concerns or misconceptions about new emerging apps such as COVID-19 contact tracing apps. These concerns or misconceptions makes them frustrated to download or use any of these apps. On the other hand, several app developers are trying to improve the privacy of their apps to attract more users to download their apps and increase adoption, as shown in Figure 7.

4.1.3 What are the main issues that prevented users from using COVID-19 apps while signing up?

Many users who decide to download and use COVID-19 apps face problems while signing up for an account to use these apps. According to our user review analysis, it was reported by many users that they were not receiving the OTP verification in some apps. Another major problem while signing up is that the app is only supporting local phone numbers. These issues were affecting students, visitors, and non-residents who do not own a local one. According to version history notes, COVID-19 app developers were releasing updates to fix OTP issues and enhance and simplify their apps' registration process, as shown in Figure 8.

4.1.4 Are COVID-19 apps accessible by all users in society? Residents Vs Non-residents: Everyone in the community should

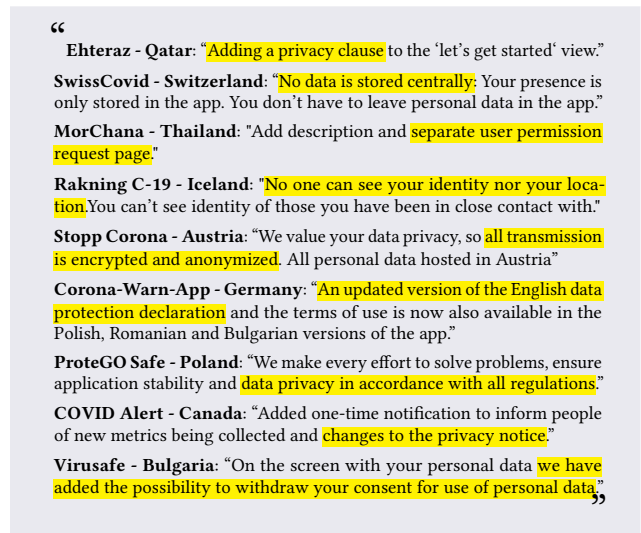


Figure 7: COVID-19 privacy statement examples

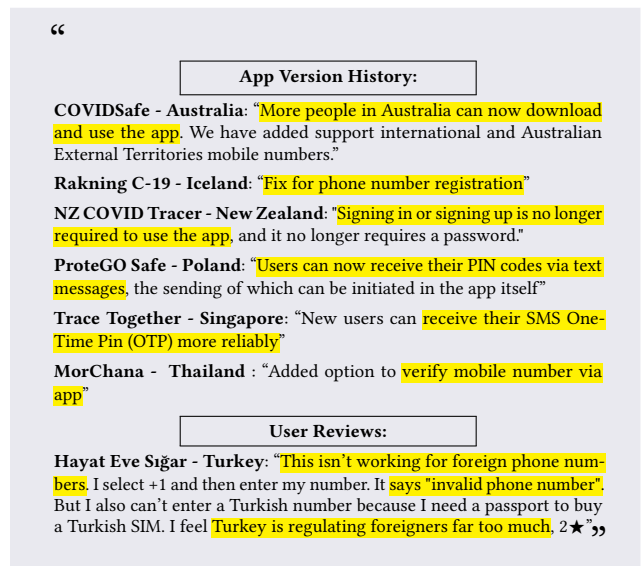


Figure 8: App access related fix and review examples

be able to download and use COVID-19 apps. Some COVID-19 apps were not accessible by non-residents since they require a national ID of some form for signing up. For example, the app was mandatory for everyone in Qatar, although you can only register for the app if you have a Qatari ID. Since visitors and non-residents did not have the ID, they failed to sign up. As shown in the following review, there were even no options for visitors in Qatar to sign up using their visa or passport, making it impossible for them to use the app: Ehteraz - Qatar: "Its not working at all. We can not login with visa/Passport. And at many places they are asking for this app. We haven't given entry to city centre. Qatar gov should provide some alternative or should allowed with visa or passport, 1★". COVID-19

app developers were releasing some app updates to make their apps more accessible to visitors and non-residents, as shown in Figure 9.

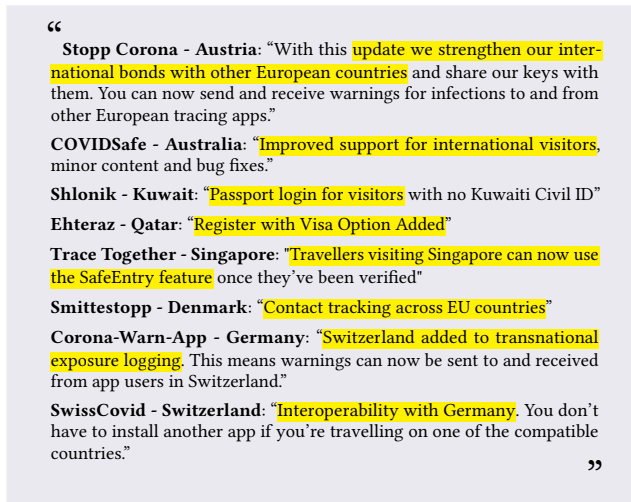


Figure 9: Accessible app fix examples

App Languages: A mobile app that supports different languages allows more people to be able to download and use it. 53% of the COVID-19 apps we analysed in our study are only supporting one or two languages. It took several months for developers of some COVID-19 apps to add translations to their apps. For example, the Danish COVID-19 app was released in June 2020 and it was only in Danish. Only in November 2020, the app developers updated the app to support the English language as well. Some users expressed in their user reviews their dissatisfaction that the app does not support English, although it is highly funded. An example: *"Like other polish apps always in polish only! I think when you spend 1 million zloty on the app, it should be good to add some zloty to have it in English!, 1★. (ProteGO Safe - Poland)"*. Some COVID-19 apps only supported the local language; hence they were not accessible by anyone who doesn't speak the native language. Many users were requesting developers in their reviews to add support to more languages in COVID-19 apps. These repetitive app requests led developers to release some app updates to fulfil these requests and make the app more accessible, as shown in Figure 10.

Different Age Groups: App stores enforce app developers to follow some guidelines to ensure that their developed apps are appropriate to the age of the targeted users. It also allows app developers to restrict some age groups from downloading or using their apps. According to our analysis, 64% of COVID-19 apps analysed in our study can be downloaded by anyone aged 4+, as shown in Table 2. While 25% of the apps can only be downloaded by users aged 12+. Only 11% of the apps restrict their apps to users above 17, which means that anyone younger than 17 years old will not be able to download or use the COVID-19 app. Some users raised the issue in their reviews, stating that their kids were unable to use COVID-19 apps and they were requesting app developers to resolve this issue. For example, *"The application does not allow registering children under 14 years of age, 4★, (Virusafe - Bulgaria)"*.

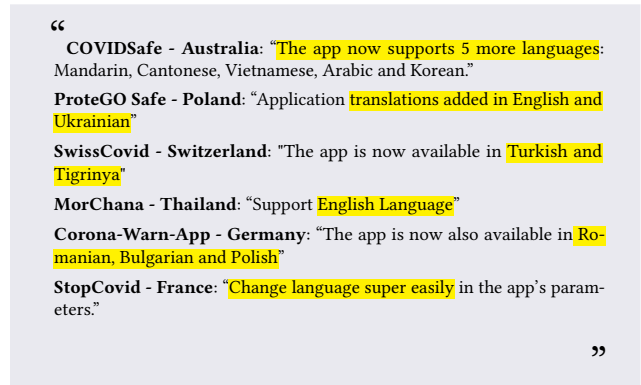
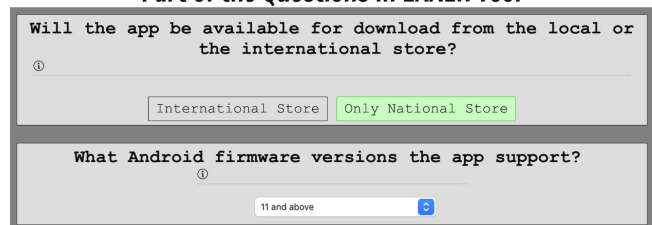


Figure 10: Language fix examples Part of the Questions in EAAER Tool



Part of the Recommendations

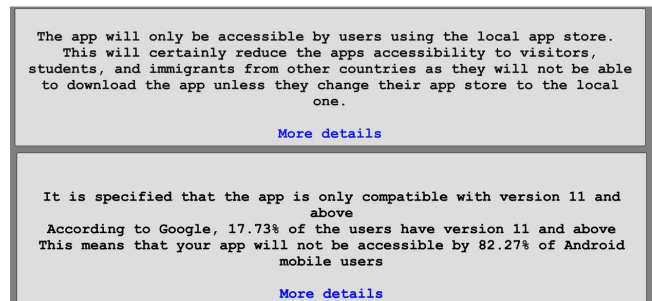


Figure 11: A screenshot of our EAAER Tool Prototype

4.1.5 Do COVID-19 apps developers interact with users?

As shown in Table 2, 61% of the analysed COVID-19 apps' developers were not interacting with users by not replying to the users' reviews. Many users have asked developers to add some features, do enhancements or fix some bugs, but there were no reply or interaction from the developers. Moreover, 47% of developers were not releasing detailed update notes, so users were not be able to identify what was updated, enhanced or added by the developer.

4.2 RQ2 – How can we provide guidance to App developers to design and build more accessible emerging apps?

4.2.1 Tool Design. Our EAAER tool is a web-tool written in Javascript, PHP, and CSS. Based on the analysis we have done in our first research question, several repetitive accessibility issues are reported in most COVID-19 apps in both user reviews and developer update notes since these apps are developed, designed and

tested in a short time span compared to other types of apps. Some of these accessibility issues were fixed by the developers of these apps, and some were not. We designed EAAER to help app developers identify these accessibility problems to reduce and possibly prevent them while developing and designing emerging apps before they are released to the public. Our tool is designed to quickly handle accessibility issues for any apps that are required to be rolled out quickly to users due to an emergency or pandemic.

EAAER asks app developers some guided questions and gives them instant evaluation and recommendations that might help them reduce or prevent common emerging app accessibility issues. Every question is designed to address one or more of the common accessibility issues that repetitively occurred across different COVID-19 apps. EAAER prompts emerging app developers with some questions that are based on key issues in emerging apps user reviews and guidance based on developers' answers and app updates. The developers start by answering a set of questions based on a range of characteristics of their planned emerging app. EAAER uses their input/answers to generate evidence-based recommendations to ensure their apps are accessible by all types of users.

The answers are completed in the form of comboboxes, checkboxes, and textfields, as shown in Figure 11. Developers are allowed to modify their answers and resubmit for updated evaluation and recommendations. When the developer finishes answering all the questions and they are ready to submit their answers, they press the "Get Advice" button to get instant feedback, which is in the form of a report and a set of recommendations based on their answers. This app evaluation and recommendations can be exported to a PDF file so they can save it for their future reference.

4.2.2 Example of EAAER Tool Usage.

Q1: At release: does the app support both iOS and Android OS? If the developer selects yes, Q1.1 will pop up. If the developer selects no, Q2 will pop up. After the developer submits all answers, and if they selected yes, EAAER will provide the following advice: *"The app will not be accessible by 72.84% of the mobile users in the case of supporting only iOS and 26.34% in the case of supporting only Android. Some apps are initially released on only one OS platform, which leads to many inconveniences for users. The Hungarian COVID-19 app is an excellent example of this issue, where it was released on GooglePlay before the AppStore, where people who owned iOS devices were not able to download the app. Later, the Hungarian COVID-19 app was removed from both stores."* EAAER then gives recommendations on how developers may better reuse code and create mobile apps that function well on various operating systems using cross-platform mobile app development tools such as Codename One, PhoneGap, Appcelerator, etc. **Q1.1: Does the app have the exact UI, features and functionalities on both operating systems?** Whether the developer selects yes or no, Q2 will pop up. If the developer selected no, EAAER will provide the following advice and recommendation: *"20% of mobile users regularly use iOS and Android simultaneously. According to most UI guidelines, it is confusing when users have inconsistent design and UI across different mobile operating systems. Developers may reuse code and create mobile apps that function well on a variety of operating systems using cross-platform mobile app development tools such as Codename One, PhoneGap, Appcelerator, etc."*

Q2: What Android firmware versions the app support? The developer will select the Android firmware from a list, then Q3 will pop up. If they selected version 11 pie for example, EAAER will provide the following advice and recommendation: *"It is specified that the app is only compatible with version 11 and above. According to Google, 17.73% of the users have version 11 and above. This means that your app will not be accessible by 82.27% of Android mobile users. To allow more people to be able to download and use the COVID-19 apps, the developers of these apps performed some updates to increase their app compatibility as shown below. You might consider changing the minSdkVersion and maxSdkversion in your app's AndroidManifest.xml file. This will allow your app to support more android versions. Please note: You have the responsibility for testing. Just lowering the Android version support level does not guarantee that your app will be fully compatible with all selected versions."*

Q3: What iOS firmware versions the app support? The developer will select the iOS firmware from a list, then Q4 will pop up. If they selected iOS 13, for example, EAAER will provide the following advice and recommendation: *"It is specified that the app is only compatible with iOS 13 and above. According to Apple, 93% of users have iOS 13 and above. This means that your app will not be accessible by 7% of iOS mobile users. To allow more people to be able to download and use the COVID-19 apps, the developers of these apps performed some updates to increase their app compatibility. Xcode provides a range of iOS version support, the max/base being whatever SDK it ships with, such as iOS 13.x w/Xcode 11.x, and the minimum being set via Deployment OS. This will allow your app to support more iOS versions. Please note: You have the responsibility for testing. Just lowering the iOS version support level does not guarantee that your app will be fully compatible with all selected versions."*

Q4: Is the privacy of the app clear to users before they download the app? Whether the developer selects yes or no, Q5 will pop up. If they selected no, EAAER will provide the following recommendation: *"Lots of mobile users have privacy concerns or misconceptions about new emerging apps such as COVID-19 contact tracing apps. This makes them frustrated and do not download or use any of these apps. Several app developers are trying to improve the privacy of their apps to attract more users. There are lots of misconceptions users might have about app privacy. These misconceptions could be handled by enhancing the privacy policies of the app and making it easy to read. It will be beneficial to encourage users to look into the app privacy section for each app on the Appstore for iOS devices and the app permissions section on GooglePlay for Android devices."*

Q5: Does the app require a telephone number in the sign up process? If the developer selects yes, Q5.1 will pop up. If the developer selects no, Q6 will pop up. **Q5.1: Does it support both local and international numbers?** Whether the developer selects yes or no, Q6 will pop up. If the developer selected no, EAAER will advise: *"The app will be inaccessible by mobile users who do not own a local telephone number. This will most likely affect visitors, immigrants, and students."*

Q6: Does it support any other sign up methods in case there are any troubles with receiving the OTP? Whether the developer selects yes or no, Q7 will pop up. If they selected no, EAAER will advise: *"The app will be inaccessible by mobile users who will not receive OTP. This most likely affects people living in remote areas or having network issues, or if the app is having any technical*

issues. You might need to consider adding other registration options, such as signing up with an email or social media account. "

Q7: Will the app be used only by citizens who live locally? If the developer selects yes, Q8 will pop up. If the developer selects no, Q7.1 will pop up. **Q7.1: Does registration require any type of identity verification such as national ID, local drivers license, passport, etc?** If the developer selects yes, Q7.2 will pop up. If the developer selects no, Q8 will pop up. **Q7.2: What about people who do not have ID such non-residents, visitors and students?** Whether the developer selects Handled or Not Handled, Q8 will pop up. If they selected Not Handled, EAAER will tell them: "Most likely the app will be inaccessible by visitors, immigrants, and students. ID requirements for these types of users needs to be handled."

Q8: Can users from all age groups use the app? Whether the developer selects yes or no, Q9 will pop up. If they selected yes, EAAER will tell them: "You need to allow the app to be downloaded by all age groups. This will need additional requirements in the development and design phases to be approved by the stores."

Q9: Is the app translated to the top languages used in the country? If the developer selects yes, Q9.1 will pop up. If the developer selects no, Q10 will pop up. **Q9.1: Enter missing languages:** The developer will write the missing language/s, then Q10 will pop up. The tool will tell them: "You need to consider adding the following language/s: (missing language/s) translations to your app."

Q10: Is the app designed/tested to be accessible by elderly/disabled people? Whether the developer selects yes or no, the "Get Advice" button will pop up. If they selected no, EAAER will show them, "Most likely the app will have accessibility design issues that might lead to problems for different types of users. Since accessibility testing is crucial for emerging apps, Web Content Accessibility Guidelines (WCAG) is the most popular guideline for webpages and mobile apps."

4.2.3 EAAER Tool Evaluation. Our EAAER tool prototype was evaluated and tested by 13 real-world app developers as shown in Table 3. They are developing apps in the following domains: eHealth, financial, government, legal practice and education. All 13 developers, who tested our EAAER prototype, indicated that the tool will be helpful for app developers/designers in addressing a range of accessibility issues before releasing their apps. 12 out of the 13 developers confirmed that they will use the tool before releasing any of their new emerging apps to the market.

Table 3: Developer evaluation of EAAER

Developer ID	Country of Residence	Age Group	Years of Experience	Development OS
D1	Australia	30-50	10+	Cross-platform
D2	Australia	50+	10+	Cross-platform
D3	Sweden	18-30	0-3	iOS
D4	Egypt	30-50	3-10	Cross-platform
D5	Australia	18-30	3-10	Cross-platform
D6	Egypt	18-30	3-10	Cross-platform
D7	Australia	30-50	10+	Cross-platform
D8	Sweden	18-30	3-10	Android
D9	Australia	30-50	10+	Cross-platform
D10	Australia	30-50	10+	Cross-platform
D11	Egypt	50+	10+	Cross-platform
D12	Sweden	18-30	3-10	Cross-platform
D13	Australia	18-30	3-10	Cross-platform

We analysed their feedback regarding EAAER and whether it prompted them to think about some accessibility app issues that they have not thought about before. We have also received feedback about adding, modifying, or removing questions from the tool. We list few feedbacks in Table 4.

Table 4: Examples of EAAER Developer Feedback

ID	Developers Feedback
D11	The distribution of android OS throughout the world was interesting. Pro active questions about disabilities of end users was good as well. App privacy settings was also interesting.
D7	I am a tester and never thought about some of the questions mentioned in the tool as the country of the app in the store.
D5	Yes, for me personally as a developer, I might be mainly focusing on the backend of the app and not be fully aware of such small details illustrated in the tool such as local/international stores issue and unlocals who will use the app.
D4	Indeed. I liked the explanations that comes after every recommendation. They are quite helpful.
D10	Perhaps cater for more diverse end users. Also, it may be better to have a set of tick boxes that app developers can tick rather than having them to answer yes / no to a number of different questions.
D3	I guess some of the questions will be unnecessary eg if the app is designed for certain age groups only (common in health for example).
D9	You need to remind users to read reviews because if they read it these problems wouldn't have existed!!
D5	Nothing. Some of these questions I never thought about them while testing. I guess a rating after submitting the answers to questions can be helpful.

5 THREATS TO VALIDITY

Internal Validity: We translated non-English user reviews to English using the Google API. In minimal instances, the translation may be incorrect, resulting in erroneous categorisation. In comparison to other categories of mobile apps, COVID-19 mobile apps have relatively fewer user reviews since many people prefer not to use these apps. Thus we can not identify accessibility problems those people might have had if they used COVID-19 apps. Many people simply leave a star rating without providing any written feedback. Some users just provide brief reviews, failing to elaborate on their app usage, complaints, or concerns. We used a large phrase dataset to classify user reviews into several categories. Our phrases may be inaccurate or miss some keywords used in user reviews. We manually checked phrases and keywords used in over 23,000 reviews to build the dataset including reviews from many other types of apps, not just those of COVID-19 apps.

External Validity: We have only included the official COVID-19 mobile apps in the study. We did not include any third-party apps or apps from different categories. Apps developed by third parties might have more/fewer accessibility issues.

Construct Validity: To automatically classify user reviews, we created a large phrase dataset. Our used words and phrases may be incorrect or omit some keywords from user reviews. To create the dataset, we manually analysed over 23,000 reviews, including reviews of various apps, not just COVID-19 ones. To identify as many accessibility issues as possible, we did the manual analysis on a large number of reviews \approx 9000. We also did a detailed manual analysis of the version history for the 30 apps included in our study. However, in 47% of the apps studied, the app developers did not provide a detailed version history. We were not able to identify what enhancements were done and what issues were fixed.

6 DISCUSSION

Based on our large-scale app review and version history notes analysis, we identified the most common accessibility issues and problems that impact emerging apps. We discuss key findings and implications for researchers and practitioners below.

Many people can not download or access COVID-19 apps.

Based on the deep large-scale analysis of the user reviews, we found out that there are still some COVID-19 apps that do not support old devices that have earlier versions of OS firmware. These devices are usually used by disabled and elderly people who are most in need of such applications. Moreover, Some COVID-19 apps cannot be downloaded from the international app store. We found that some COVID-19 apps are only available for certain country stores, so visitors could not download them as their store is different from the country they are visiting. In addition to, the privacy and data-handling policies of some COVID-19 apps are not clear to users. Some COVID-19 apps have vague data policies and data use agreements, which make it very hard to understand whether the app uses/saves certain data or not. That reason pushes some people to stop using the app or even delete it.

Many COVID-19 app users were unable to register. Many COVID-19 apps do not support different ways for signing up. Most COVID-19 apps use only one method to sign up. If someone does not have the exact requirements needed for this method, they will not be able to register at all. It frequently occurred, especially with visitors and they ended up not using the app. There are also problems with receiving the OTP to complete registration. There are a few reasons for the One-Time Password (OTP) method to fail. If there is a network issue or the user is not receiving a signal or entered an international number, etc. This led some users to not being able to sign up and use the app. Adding to that, there is no support for international telephone numbers during the registration process.

Several COVID-19 apps only support national numbers and/or require national ID. This by default prevents a large number of people, including visitors, tourists, and students, from using the apps. Also, the App requiring users to have a local ID to verify their identity during registration. Some COVID-19 apps require a national ID as the first step to register into the app. This prevents all international students, visitors, scholars, etc., from using the app as they usually do not have a valid local ID.

Many COVID-19 apps only support the local country language. It is almost impossible for anyone who does not know a language to use these apps. There are several monolingual or bilingual COVID-19 apps, which prevent people who do not understand the language from using them.

Some COVID-19 apps do not support all age-groups. Some COVID-19 app developers set their app to be downloaded only by specific age groups. This prevents people from other age groups from downloading and using these apps. On the other hand, we identified that there are new features that can only be performed by the newer generation, such as swiping up, two swipes to the right, holding and light pressing, etc. These features are very hard to understand and to be done by the older generation.

Several COVID-19 apps are not tested to be accessible by elderly or disabled users. Some COVID-19 app developers did not consider adding the elderly or disabled phase of testing in their

User Acceptance Testing (UAT) and signed off on the app to be pushed to production and go live without having it tested for that. COVIDSafe was the only app included in our study to indicate that they enhanced accessibility to WCAG 2.1 Level AA compliant.

No tools or guidelines have been found to reduce/prevent accessibility issues while developing emerging apps. Our EAAER tool can be used as a mandatory requirement for pushing apps to the stores, similar to what is happening with unit testing, etc. As evidenced in our large-scale analysis, some COVID-19 apps need significant accessibility enhancements. From a software engineering perspective, more research needs to be done on how to automatically encapsulate the process of testing and identifying accessibility issues while the app is still in the development and design phases without the need for any manual input from app developers.

7 RELATED WORK

Users reviews analysis has been done in several studies to understand users' feedback regarding the usage of several categories of mobile apps [13, 18, 21–23, 25, 27, 48]. In [40], an exploratory study was conducted to understand what factors would influence users' decisions to post an app review. The authors of [20] looked at a variety of components that may influence the app ratings submitted in the reviews, including the relationship between rating, price, and the number of downloads. Another study [7], suggested a computational structure for extracting and ranking insightful reviews using a semi-supervised algorithm. For mining users' opinions and satisfaction, the authors created a semi-automated keyword-based technique to analyse user reviews [42].

An analysis of COVID-19 app user reviews has been conducted in some studies. In [36], nearly one thousand reviews have been manually analysed to identify users' sentiments and general satisfaction levels with using the Irish COVID-19 app. In [19], nearly two million user reviews were analysed to identify the differences between users' privacy concerns in social media apps versus COVID-19 apps. In [3] the authors analysed the reviews of 16 COVID-19 apps to understand the satisfaction levels among users and if their reviews were positive or not.

Some studies [5, 41, 46] have been done to include mandatory functional unit test cases to ensure that the apps are functioning as expected. These studies focused on functional requirements; however, no work has yet been done to identify accessibility issues while using COVID19 apps and what issues prevented users from using these emerging apps. Moreover, no study has been conducted so far to relate user reviews' analysis to apps' version history notes. In our work, we conducted two types of analysis to properly comprehend the range of significant accessibility issues raised by users of COVID-19 apps. First, we extracted, translated, and automatically classified 225,708 user reviews from Google Play and the App Store for 30 different COVID-19 apps. After that, a manual analysis of 9075 user reviews for these apps was conducted. Second, we manually analysed each app's version history, updated app descriptions, and developer information. Finally, we developed a new advisory tool (EAAER) that prompts developers for a range of characteristics of their planned emerging app, and uses their answers to generate evidence-based recommendations to ensure their apps will be accessible by all types of users before deployment.

8 SUMMARY

During the COVID-19 pandemic, a large number of "emerging apps" were developed and deployed quickly to handle an urgent situation. Many more emergency apps, such as those providing advice and guidance during bushfires, floods, and other pandemics, are likely to be developed in the future. We looked at the app reviews and version history notes for 30 COVID-19 apps which were produced in a hurry in 2020. We discovered a wide range of accessibility concerns, not just those relating to traditionally challenging end-user accessibility, but also the ability to register, access, download, and use apps from various app stores in various regions and for various end-users. Based on this large-scale analysis, we developed a new advisory tool to help emerging app developers in avoiding many of the widespread accessibility issues that exist in COVID-19 apps. A user evaluation of our prototype tool was performed by 13 real-world app developers, it indicated that our tool would help developers to fix many of these accessibility issues and problems before releasing an emerging app to the mobile app market.

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REFERENCES

- [1] Daniel Allington and Nayana Dhavan. 2020. The relationship between conspiracy beliefs and compliance with public health guidance with regard to COVID-19. (2020).
- [2] Apple. 2021. *App Store*. Retrieved Feb 2, 2022 from <https://www.apple.com/au/app-store/>
- [3] Muneera Bano, Chetan Arora, Didar Zowghi, and Alessio Ferrari. 2021. The Rise and Fall of COVID-19 Contact Tracing Apps: when NFRs Collide with Pandemic.. In *29th IEEE International Requirements Engineering Conference (RE)*. IEEE.
- [4] Surekha Borra. 2020. COVID-19 apps: Privacy and security concerns. In *Intelligent Systems and Methods to Combat Covid-19*. Springer, 11–17.
- [5] Laura Bradford, Mateo Aboy, and Kathleen Liddell. 2020. COVID-19 contact tracing apps: a stress test for privacy, the GDPR, and data protection regimes. *Journal of Law and the Biosciences* 7, 1 (2020), Isaa034.
- [6] Eugene Y Chan and Najam U Saqib. 2021. Privacy concerns can explain unwillingness to download and use contact tracing apps when COVID-19 concerns are high. *Computers in Human Behavior* 119 (2021), 106718.
- [7] Ning Chen, Jialiu Lin, Steven CH Hoi, Xiaokui Xiao, and Boshen Zhang. 2014. AR-miner: mining informative reviews for developers from mobile app marketplace. In *Proc. 36th Int. Conf. on software engineering*. 767–778.
- [8] Marco Ciotti, Massimo Ciccozzi, Alessandro Terrinoni, Wen-Can Jiang, Cheng-Bin Wang, and Sergio Bernardini. 2020. The COVID-19 pandemic. *Critical reviews in clinical laboratory sciences* 57, 6 (2020), 365–388.
- [9] Laura Di Domenico, Giulia Pullano, Chiara E Sabbatini, Pierre-Yves Boëlle, and Vittoria Colizza. 2020. Impact of lockdown on COVID-19 epidemic in Île-de-France and possible exit strategies. *BMC medicine* 18, 1 (2020), 1–13.
- [10] John Drury and S Tekin Guven. 2020. Emergencies and disasters. *Together apart the psychology of COVID-19* (2020), 97–101.
- [11] Stuart Ellis, Peter Kanowski, and RJ Whelan. 2004. National inquiry on bushfire mitigation and management. (2004).
- [12] Mattia Fazzini, Hourieh Khalajzadeh, Omar Haggag, Zhaoqing Li, Humphrey Obie, Chetan Arora, Waqar Hussain, and John Grundy. 2022. Characterizing Human Aspects in Reviews of COVID-19 Apps. In *9th IEEE/ACM International Conference on Mobile Software Engineering and Systems 2022 (MobileSoft 2022)*.
- [13] Necmiye Genc-Nayebi and Alain Abran. 2017. A systematic literature review: Opinion mining studies from mobile app store user reviews. *Journal of Systems and Software* 125 (2017), 207–219.
- [14] Google. 2021. *Google Play*. Retrieved Feb 2, 2022 from <https://play.google.com/store/>
- [15] Australian Government. 2020. *2019–20 Australian bushfires—frequently asked questions: a quick guide*. Retrieved Feb 2, 2022 from https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/rp/rp1920/Quick_Guides/AustralianBushfires/
- [16] The Guardian. 2013. *FireReady bushfire app sent out false alerts, users complain*. Retrieved Feb 2, 2022 from <https://www.theguardian.com/world/2013/dec/30/fire-ready-bushfire-app-sent-out-false-alerts-users-complain/>
- [17] Tobias Guggenberger, Jannik Lockl, Maximilian Röglinger, Vincent Schlatt, Johannes Sedlmeir, Jens-Christian Stoetzer, Nils Urbach, and Fabiane Völter. 2021. Emerging Digital Technologies to Combat Future Crises: Learnings From COVID-19 to be Prepared for the Future. *International Journal of Innovation and Technology Management* (2021), 2140002.
- [18] Emitza Guzman and Walid Maalej. 2014. How do users like this feature? a fine grained sentiment analysis of app reviews. In *2014 IEEE 22nd international requirements engineering conference (RE)*. IEEE, 153–162.
- [19] Omar Haggag, Sherif Haggag, John Grundy, and Mohamed Abdelrazek. 2021. COVID-19 vs Social Media Apps: Does Privacy Really Matter?. In *2021 IEEE/ACM 43rd International Conference on Software Engineering: Software Engineering in Society (ICSE-SEIS)*. IEEE, 48–57.
- [20] Claudia Iacob, Varsha Veerappa, and Rachel Harrison. 2013. What are you complaining about?: a study of online reviews of mobile applications. In *27th International BCS Human Computer Interaction Conference (HCI 2013)* 27. 1–6.
- [21] Nishant Jha and Anas Mahmoud. 2019. Mining non-functional requirements from app store reviews. *Empirical Software Engineering* 24, 6 (2019), 3659–3695.
- [22] Timo Johann, Christoph Stanik, Walid Maalej, et al. 2017. Safe: A simple approach for feature extraction from app descriptions and app reviews. In *2017 IEEE 25th International Requirements Engineering Conference (RE)*. IEEE, 21–30.
- [23] Huiying Li, Li Zhang, Lin Zhang, and Jufang Shen. 2010. A user satisfaction analysis approach for software evolution. In *2010 IEEE International Conference on Progress in Informatics and Computing*, Vol. 2. IEEE, 1093–1097.
- [24] Jinfeng Li and Xinyi Guo. 2020. COVID-19 contact-tracing apps: A survey on the global deployment and challenges. *arXiv preprint arXiv:2005.03599* (2020).
- [25] Mengmeng Lu and Peng Liang. 2017. Automatic classification of non-functional requirements from augmented app user reviews. In *Proceedings of the 21st International Conference on Evaluation and Assessment in Software Engineering*. 344–353.
- [26] R Harry Luke, Alan Grant McArthur, et al. 1978. Bush fires in Australia. *Bush Fires in Australia*. (1978).
- [27] Walid Maalej, Zijad Kurtanović, Hadeer Nabil, and Christoph Stanik. 2016. On the automatic classification of app reviews. *Requirements Engineering* 21, 3 (2016), 311–331.
- [28] Joshua C Morganstein, Carol S Fullerton, Robert J Ursano, Darrin Donato, and Harry C Holloway. 2017. Pandemics: health care emergencies. *Textbook of disaster psychiatry* (2017), 270–284.
- [29] Jessica Morley, Josh Cows, Mariarosaria Taddeo, and Luciano Floridi. 2020. Ethical guidelines for COVID-19 tracing apps.
- [30] ABC News. 2021. *The COVIDSafe app has cost \$9m to date, but it hasn't uncovered any close contacts during the current outbreaks*. Retrieved Feb 2, 2022 from <https://www.abc.net.au/news/2021-09-30/covidsafe-app-cost-hasnt-uncovered-close-contacts-2021-outbreaks/100499870/>
- [31] Editors of News.com.au. 2018. *Residents left stranded by useless smartphone app during 'catastrophic' bush fire conditions*. Retrieved Feb 2, 2022 from <https://www.news.com.au/technology/environment/residents-left-stranded-by-useless-smartphone-app-during-catastrophic-bush-fire-conditions/news-story/ae48b58c62fe3cf69f35c9f2c1346a8/>
- [32] Patrick Howell O'Neill. 2020. *No, coronavirus apps don't need 60% adoption to be effective*. Retrieved Oct 16, 2020 from <https://www.technologyreview.com/2020/06/05/1002775/covid-apps-effective-at-less-than-60-percent-download>
- [33] Brian A O'Shea and Michiko Ueda. 2021. Who is more likely to ignore experts' advice related to COVID-19? *Preventive medicine reports* 23 (2021), 101470.
- [34] Douglas Paton, Gail Kelly, Petra T Burgelt, and Michael Doherty. 2006. Preparing for bushfires: understanding intentions. *Disaster Prevention and Management: an international journal* (2006).
- [35] Enrico Louis Quarantelli. 2000. Emergencies, disasters and catastrophes are different phenomena. (2000).
- [36] Kaavya Rekanar, Ian R O'Keefe, Sarah Buckley, Manzar Abbas, Sarah Beecham, Muslim Chochlov, Brian Fitzgerald, Liam Glynn, Kevin Johnson, John Laffey, et al. 2021. Sentiment analysis of user feedback on the HSE's Covid-19 contact tracing app. *Irish Journal of Medical Science (1971-)* (2021), 1–10.
- [37] Marion Lara Tan, Raj Prasanna, Kristin Stock, Emma Hudson-Doyle, Graham Leonard, and David Johnston. 2017. Mobile applications in crisis informatics literature: A systematic review. *International journal of disaster risk reduction* 24 (2017), 297–311.
- [38] Chrisa Tsinaraki, Irena Mitton, Marco Minghini, Marina Micheli, Alexander Kotsev, Lorena Hernandez Quiros, Fabiano-Antonio Spinelli, Alessandro Dalla Benetta, and Sven Schade. 2021. Mobile Apps to Fight the COVID-19 Crisis. *Data* 6, 10 (2021), 106.
- [39] Oxford University. 2020. *Digital contact tracing can slow or even stop coronavirus transmission and ease us out of lockdown*. Retrieved Oct 16, 2020 from <https://www.research.ox.ac.uk/Article/2020-04-16-digital-contact-tracing-can-slow-or-even-stop-coronavirus-transmission-and-ease-us-out-of-lockdown>

- [40] Rajesh Vasa, Leonard Hoon, Kon Mouzakis, and Akihiro Noguchi. 2012. A preliminary analysis of mobile app user reviews. In *Proc. 24th Australian Computer-Human Interaction Conference*. 241–244.
- [41] Kerstin Noelle Vokinger, Vasileios Nittas, Claudia M Witt, Sara Irina Fabrikant, and Viktor Von Wyl. 2020. Digital health and the COVID-19 epidemic: an assessment framework for apps from an epidemiological and legal perspective. *Swiss Medical Weekly* (2020).
- [42] Phong Minh Vu, Tam The Nguyen, Hung Viet Pham, and Tung Thanh Nguyen. 2015. Mining user opinions in mobile app reviews: A keyword-based approach (t). In *2015 30th IEEE/ACM Int. Conf. on Automated Software Engineering (ASE)*. IEEE, 749–759.
- [43] Michel Walrave, Cato Waeterloos, and Koen Ponnet. 2020. Adoption of a contact tracing app for containing COVID-19: a health belief model approach. *JMIR public health and surveillance* 6, 3 (2020), e20572.
- [44] Josh Whittaker and David Mercer. 2004. The Victorian bushfires of 2002–03 and the politics of blame: a discourse analysis. *Australian Geographer* 35, 3 (2004), 259–287.
- [45] Worldometers. 2021. *COVID-19 CORONAVIRUS PANDEMIC LIVE UPDATES*. Retrieved Feb 2, 2022 from <https://www.worldometers.info/coronavirus/>
- [46] Yanxiang Yang and Joerg Koenigstorfer. 2020. Determinants of physical activity maintenance during the Covid-19 pandemic: a focus on fitness apps. *Translational behavioral medicine* 10, 4 (2020), 835–842.
- [47] ZDNet. 2021. *Australia's COVIDSafe app costs AU\$100,000 per month to keep running*. Retrieved Feb 2, 2022 from <https://www.zdnet.com/article/australias-covidsafe-costs-au100000-per-month-to-keep-running/>
- [48] Sebastian Zimmeck, Ziqi Wang, Lieyong Zou, Roger Iyengar, Bin Liu, Florian Schaub, Shomir Wilson, Norman M Sadeh, Steven M Bellovin, and Joel R Reidenberg. 2017. Automated Analysis of Privacy Requirements for Mobile Apps. In *NDSS*.