COVID-19 DASHBOARD FUNCTIONALITY & DESIGN:
Assessing Dashboard Design Service Providers for Health Disaster Response

by

LUCINDA S. ROBERTS

A THESIS

Presented to the UO Department of Geography
and the Robert D. Clark Honors College
in partial fulfillment of the requirements for the degree of
Bachelor of Science

June 2023

An Abstract of the Thesis of

Lucinda Roberts for the degree of Bachelor of Science
in the Department of Geography to be taken June 2023

Title: COVID-19 Dashboard Functionality and Design

Approved: ____________*Carolyn Fish, Ph.D.*________________
Primary Thesis Advisor

When disaster strikes, data visualizations are used as quick ways to concisely distill timely information to civilians. Amidst the COVID-19 pandemic, data-driven dashboards played a disproportionately large role in quickly collecting, processing, and conveying preliminary data to citizens. After the Johns Hopkins COVID-19 dashboard went viral, individual public health departments across the world realized the importance of distilling and delivering real-time data to citizens and decision makers. The widescale proliferation of dashboards across emergency response groups has only recently been made possible thanks to a business model in the software industry known as Platform as a Service, or PaaS, providers, which provide the data hosting, application development, and graphical interfaces for non-technical experts to deploy dashboards without an extensive background in web development. What the PaaS providers offer in ease-of-use, however, is traded against their limitations in functionality and accessibility. In this thesis, I used content analysis to perform a systematic review of 24 international COVID-19 data dashboards to understand international variation in COVID-19 dashboard design and to offer feature recommendations for software companies to incorporate into their PaaS platforms.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

In December of 2019, a new Coronavirus (COVID-19) was reported in Wuhan, Hubei Province, China. The virus notably caused severe acute respiratory syndrome (SARS) and it was officially named SARS-CoV-2 (Zhao *et al*. 2021). Despite strict attempts to control the virus's spread, the disease quickly migrated to other provinces in China, and, by early February 2020, COVID-19 had killed over 1,000 people worldwide (CDC COVID Timeline). In January 2020, Ensheng Dong, a graduate student in Systems Engineering at Johns Hopkins University who had family near Wuhan, approached Dr. Lauren Gardner, his faculty advisor, hoping to find a way conceptualize the spread of COVID-19. Dong had a master's degree in Geography and Statistics and had previously interned at Esri- a geospatial technology company which builds the leading Geographic Information Science (GIS) software and is a PaaS provider. Amidst the uncertainty of the COVID-19 pandemic in early 2020, Gardner and Dong began collecting and assimilating the spatial data into what would become the Johns Hopkins COVID-19 Dashboard, later renamed the Johns Hopkins Covid Resource Center (Milner 2020). After the Hopkins COVID-19 dashboard skyrocketed in popularity, individual public health departments and organizations across the world realized the utility of amassing and distributing their data to the public. The dissemination of this rapidly changing data about the COVID-19 pandemic was possible through data-driven dashboards and online data portals.

Through the development of the Hopkins COVID-19 Dashboard, it was clear that when disaster strikes, data-driven dashboards are used as quick ways to concisely distill timely information to citizens with data visualizations. When the SARS-CoV-2 pandemic (COVID-19) started spreading internationally, experts in data visualization played a disproportionately large role in quickly collecting, processing, and disseminating preliminary data to citizens through these data dashboards of disease rates. Throughout the months following the disease outbreak, data visualization experts continued to refine their communications strategies in alignment with public health policies at the time. The development and deployment of data dashboards is a technologically-intensive process which has recently become accessible through Platform as a Service — or PaaS — providers, which handle the infrastructural challenges of creating, serving, and deploying a dashboard so that experts from other domains can create dashboards without an extensive background in web development. While dashboard-building platforms provide useful infrastructural support and expand the number of people who can create a dashboard, their ease-of-use compromises important functionality and design flexibility that dashboard coders have leveraged for clarity and accessibility (Torkington 2023). The COVID-19 pandemic clearly demonstrated the importance of dashboard building as a cornerstone of comprehensive emergency response communications strategy yet analysis of what is suggested in the literature and what was actually provided in these data dashboards across the globe is less known. In this thesis, I analyzed the variability in international COVID-19 data dashboard functionality to identify the key features that PaaS providers should provide to be more useful tools amidst public health emergencies.

PaaS providers allow users on-demand access to the data-hosting servers and graphical user interfaces (GUIs) necessary to design and release online applications without requiring the technical background to develop every level of the application. Common PaaS include Esri's ArcGIS Dashboard, Microsoft's Power BI, Google's Looker Studio, and Salesforce's Tableau. The proliferation of PaaS means subject-level domain experts, such as public health officials, no longer have to specialize in web development or data visualization to create communications that rely on dashboards. Instead, these experts can use a PaaS to create visualizations that inform public health recommendations and educate the public without having to overcome the technical hurdles of developing a data visualization.

Although PaaS have made dashboard creation easier, the science and art of data visualization is still an incredibly nuanced field, and the ways that an information system is designed can dramatically impact the user's perception of the data (Griffin 2020). The Johns Hopkins COVID-19 dashboard, for example, used an iterative design process to make sure the data's visualization matched the story of COVID's spread, In an interview about how he built the Hopkins COVID Resource Center dashboard, Ensheng Dong explained how the dashboard developed over time,

> We're constantly adjusting the [size of the] dot. We added a few other maps besides the cumulative and confirmed cases, such as active cases, to clearly communicate the data we were collecting and sharing. If more people in your country are recovering, you refer to that map—the dots are smaller, and you feel better. (Milner 2020).

He also explained that they had to go back and revise early design decisions in the dashboard, such as the decision to map everything to the finest spatial scale available. Eventually, they had every county in the United States mapped, while in other geographically large countries such as Russia, they mapped only at a state-level. Visually, this made the US appear "coated" in red virus, while Russia's infections looked relatively sparce (Milner 2020). The decisions that go into a dashboard layout may feel intuitive for a person without a design background, but each of these decisions behind how the data get visualized—from data scale to color to hosting platform—have tradeoffs in communication, loading speeds, and project feasibility.

Research Questions

In this research project, I reviewed 24 dashboards made by 24 different countries' national public health agencies showing COVID-19 disease and vaccination efforts with the goal of understanding the communication styles of international entities during the COVID-19 pandemic. Understanding differences in communication styles across countries who experienced large COVID waves in early 2020 is important in evaluating what types of information were available, and, importantly, *how* it was made available to decision-makers, policymakers, and the public through these dashboards. My preliminary analysis showed that differences in dashboard design were more likely attributable to underlying technology (e.g. PaaS capabilities) rather than differences in design decisions attributable to different COVID-19 policies. Thus, in this thesis, I want to better understand how dashboards differed in dashboard design and functionality to give recommendations for PaaS feature development. Given this I ask the following research questions:

> RQ1: How did COVID-19 dashboards created by national government organizations differ in their design?
>
> RQ2: How did national COVID-19 dashboards differ in the functionality for data download, language localization, and archivability? What impact did Platform as a Service (PaaS) providers have on the differences in functions between different countries' COVID-19 dashboards?
>
> RQ3: What are common workflows PaaS providers should consider supporting for health disaster response dashboards?

In March of 2023, three years after the launch of the initial COVID-19 dashboard, Johns Hopkins University announced it would cease its live data tracking and reporting for COVID-19 response (Torkington 2023). The Johns Hopkins dashboard is not the only case of dashboards and data portals about COVID-19 being discontinued. The closing of these online resources was driven by a confluence of events: the decreased public funding to collect data, the ceasing of converging data from different people collecting COVID-19 test results, increased at home testing, to decreased funding for data collection (Torkington 2023). The discontinuation of the Johns Hopkins COVID-19 dashboard came at a time when the public and public health institutions were starting to direct resources and attention away from the COVID-19 pandemic. This discontinuation is particularly distressing for data visualization researchers who are interested in questions about what data was made available and how, because many dashboards cannot be preserved on traditional web archiving platforms. To learn where we can improve in response to future global health crises, we need to understand what we did in response to the initial outbreak of COVID-19. Capturing the state of COVID-19 dashboards at this moment is valuable for providing a retrospective look on COVID-19 communication before these key ephemera are permanently removed from the public eye.

Chapter 2: Literature Review

This thesis analyzes the content of 24 international COVID-19 dashboards to assess differences in their design and their functionality. To provide better context for this work, this chapter defines what a dashboard is, provides a case study in how COVID-19 communication changes across borders, outlines other features that are crucial in dashboard design such as language localization and data download options, and gives an overview of past research into COVID-19 dashboard content.

What is a Dashboard?

Although dashboards have become ubiquitous tools used to display visuals that quickly convey information for decision making on a screen, there remains little substantial scholarly agreement on what constitutes a dashboard (Wexler 2017, Sarikaya *et al.* 2019, Bach 2022). Few (2007) defined a dashboard as "a visual display of the most important information needed to achieve one or more objectives; consolidated and arranged on a single screen so the information can be monitored at a glance." A decade later, Wexler *et al.* (2017) take a more generalized definition and move away from the paradigm that a dashboard must occupy a single screen, instead saying, "a dashboard is a visual display of data used to monitor conditions and/or facilitate understanding." Bach *et al.* (2022) emphasize that dashboards do not just convey *data* but *information* (*i.e.* knowledge derived from data), "dashboards do not simply reflect data, but are a purposefully created lens through which data must be seen and engaged with."

Dashboards can be used by a wide range of institutions to track progress on goals, identify trends, and make data-driven decisions. Their flexibility is what makes them as useful as they are challenging to define. The diversity of their applications reflects how a dashboard's design can have many configurations based on the context, audience, and resource-limitations of the designer. In this thesis, I echo Wexler *et al*.'s (2017) and Bach *et al*.'s (2022) assessment of dashboard diversity and remain open-minded about what a dashboard can be to consider a wider range of international design choices. Thus, in this thesis I define a ***dashboard*** *as a display of information, presented through a purposefully curated lens, used to monitor conditions and/or facilitate understanding about a topic*.

Dashboard design has been looked at in the past by Few (2007), Sarikaya *et al.* (2019), Wexler *et al.* (2019). Bach *et al*. (2022) provides the most recent and thorough overview of the dashboard elements through a taxonomy of dashboard design patterns. They divide out the different aspects of a dashboard design into 1) Data, 2) Structure, 3) Visual Representation, 4) Page Layout, 5) Screenspace, 6) Interaction, 7) Meta Data, and 8) Color, which are summarized in *Figure 1*. Given the importance and use of dashboards for the COVID-19 pandemic, Bach *et al.*'s taxonomy provides a helpful way to categorize and analyze the design, data availability, and functionality of these types of dashboards to improve these data portals for future global health crises.

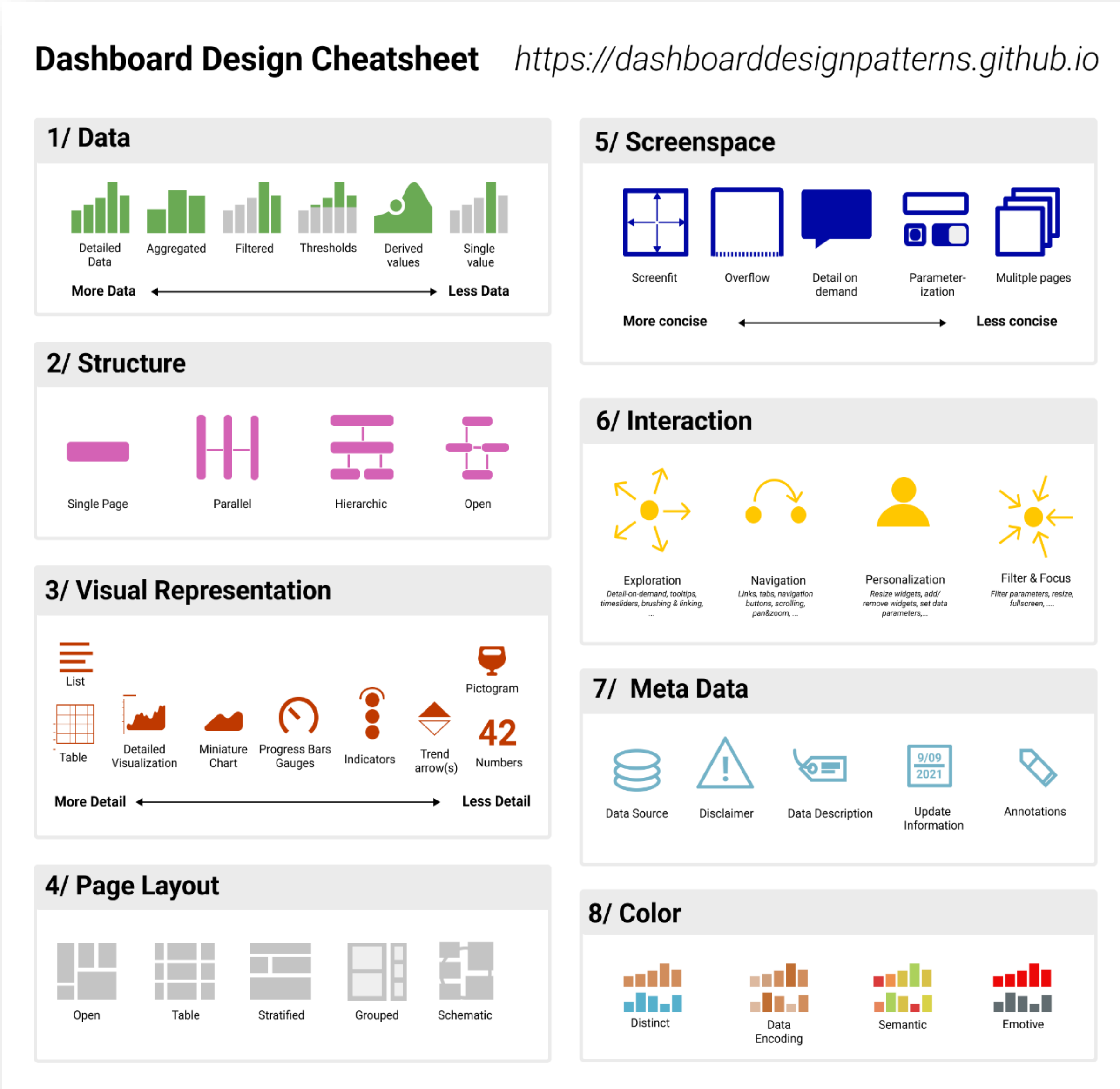


Figure 1. Bach *et al.*'s (2022) taxonomy of dashboard design patterns.

Used with permission. This image is available for download as a PDF at https://dashboarddesignpatterns.github.io

Future Data Forecasts

After the Hopkins COVID-19 dashboard skyrocketed in popularity, individual public health departments and organizations realized the utility of amassing and distributing their data to the public, and the concept of making a dashboard of COVID-19 spread became popular globally (Rajabiford *et al.* 2021). However, the communication strategies each country uses are shaped heavily by the social and political environments in each infected nation (Nicher 2008, Harris & White 2019). When the COVID-19 pandemic spread globally, not only did it move across geographic boundaries, but it encountered a cultural and political landscape which drastically changed how public health messaging had to respond to the new outbreak.

One case study in national communication strategies was a comparative analysis by Au *et al.* (2022) on the ways that officials in China and the United States handled public health communication differently. In China, according to Au *et al.* (2022), the shared memory of the 2003 SARS pandemic dominated the communications strategies in the country. COVID-19 brought back memories of how local Chinese officials had downplayed the early SARS pandemic with disastrous consequences for how the pandemic would play out, and it recalled stories of a pandemic that was eventually contained through intensive government intervention (Au *et al.* 2022). The collective memory of the SARS pandemic also gave the public a familiar cast of doctors and public health officials, such as Zhong Nanshan, who had gained public trust for their choices and actions during the SARS pandemic (Au *et al.* 2022). Au *et al.* (2022) refer to this collective memory of a past pandemic as an *expert narrative,* which shaped the COVID-19 communication landscape in China. By making the case that COVID-19 was "SARS-like, but not SARS," Chinese officials were able to establish a more cohesive expert narrative once the COVID-19 outbreak was escalated to national attention.

In contrast with the Chinese public health narratives, public health officials in the United States could not appeal to any shared memories of pandemic spread, which lead to what Au *et al.* (2022) refer to as a *contested narrative*. While early communications strategies at the beginning of the COVID-19 pandemic tried to recall a myriad of diseases ranging from the 1920s Spanish Flu to the 2010s H1N1 epidemic, these comparisons fell flat due to the lack of shared, collective experiences of both of those previous pandemics. The past provided no specific implications for the future, thus experts in the US relied on models and projections of future disease spread to show the potential implications of public health interventions (Au *et al*. 2022). The lack of cohesive expert narratives amidst the outbreak of COVID-19 shifted the burden to data scientists and disease modelers to come up with publicly salient statistics and data visualizations that would convey the potential severity of the COVID-19 pandemic in the United States.

Language Localization

The communication of information must be accessible to all potential users of that information. Dashboard design for a global health crisis such as COVID-19 is no different. Thus, *localization,* the process of adapting software or content to meet the linguistic and cultural requirements of a particular region (Madill, "What is Localization?") is incredibly important for providing data about current disease counts. In 2021, Momenipour *et al.* found in a systematic review of 16 states' COVID-19 dashboards that US dashboards rarely incorporated second language options into their dashboard design. Language localization tools typically involve the use of language packs, which contain translations of the dashboard interface and content into different languages. In addition to language localization, webpages and software may also incorporate other localization features, such as date and time formatting, currency symbols, and units of measurement ("Localization Introduction" 2022). These cultural adaptations are especially important in dashboard layout and design because they can help users better understand and analyze data, as they are presented in a format that is familiar and relevant to their region or language. Coming off as authoritative and understandable across cultural barriers helps to establish trustworthiness in data communication (Griffin 2020).

Data Download Options

In addition to localization, dashboards that provide information about a pandemic often allow users to download data that are important for ensuring that users can work with and derive new insights from public datasets (Momenipour *et al.* 2021). Data download options in a variety of formats, such as CSV, Excel, or PDF can facilitate data sharing, collaboration, proper citation, and help track data provenance (Praharaj *et al.* 2022). Data download options allow dashboard designers to enable users to export and download data in various formats, facilitating offline access, data sharing, and compliance with data protection regulations. By allowing users to download data, Young and Kitchin (2020) found that the provision of data download options helped to affirm users' engagement with the dashboard content. Praharaj *et al.* (2022) found in a systematic analysis of 68 dashboards of COVID-19 in US that 33 of the dashboards, or 48%, did not include options for the user to download data from the dashboard.

Evaluating COVID-19 Dashboard Design

The recent increase in the number of data dashboards has led to an increase in scholarly research and review of these data mediums (Praharaj *et al.* 2022). In addition, as pushes for open-access data have grown for both government transparency and to allow citizens use of their own data, understanding how these data are made available are increasingly important. For instance, Momenipour *et al.* (2021) evaluated 16 US states' COVID-19 public health dashboards and provided a list of recommended features based on their observations. In 2022, Praharaj *et al.* similarly performed a systematic analysis of 68 US states' dashboards and used the results to create a prototypical exemplary dashboard of COVID-19 response. In both cases, Momenipour *et al.* and Praharaj *et al.* performed some version of a *content analysis*. A content analysis is a method of systematically analyzing the contents of a visual image that was originally adapted from written and spoken text (Rose 2016). The process of performing a content analysis is methodologically explicit and encompasses best practices for a) selecting images b) devising categories for the images c) coding the images d) analyzing the results (Rose 2016). These analyses are common among researchers trying to understand trends in data visualization strategies (Fish 2020, Fish and Kreitzberg 2022, Praharaj *et al.* 2022, Momenipour *et al.* 2021), as well as general communications strategies (Tagliacozzo *et al.*2022). In the following chapters I use this method to explore COVID-19 dashboards provided by national governments across the globe to analyze variability in international COVID-19 data dashboard functionality and design.

Chapter 3: Methods

The goal of this research is to quantify the characteristics of international COVID-19 dashboards and to offer recommendations for features of PaaS providers based on those characteristics. To address my research questions, I performed a content analysis of 24 countries' dashboards showing COVID-19 disease spread and/or vaccination distribution. A content analysis is a method of systematically analyzing the contents of a visual image that was originally adapted from written and spoken text (Rose 2016). The process of performing a content analysis is methodologically explicit and encompasses best practices for a) selecting images b) devising categories for the images c) coding the images d) analyzing the results. In this case, the goal of coding the COVID-19 dashboards was to have a way to systematically quantify the characteristics of COVID-19 dashboards to inform later recommendations.

Selecting dashboards

I identified the top 45 countries with the highest reported incidence of COVID-19 disease as of September 1st, 2020, approximately six months after COVID-19 spread internationally. I chose this set of countries because these are the jurisdictions I identified to be most likely to need a comprehensive COVID-19 communications strategy, and therefore were the most likely to create COVID-19 dashboards to communicate with their citizens and provide data for decision makers.

For each of the countries in my list, I performed a keyword search in English using Google's search engine for "[country name] COVID dashboard" and progressively tried different keywords such as “public health ministry” and “case counts”. If those keywords in English did not return a result, I used Google Translate to put the same keywords into that country’s official language. If neither of those strategies worked, I searched for the individual country’s public health department and checked to see if there were links to webpages specific to COVID-19.

To qualify as a COVID-19 dashboard for the purposes of my study, the dashboard had to 1) meet the definition of a dashboard defined in “Chapter 2” and 2) display data relating to COVID-19 disease progression or vaccine disbursement in the particular country. Several countries appeared to have dashboards which focused on disease proliferation, which then pivoted either entirely or partially to include vaccine information, which meant it was impossible in many cases to isolate dashboards about either disease spread or vaccination exclusively. Once a webpage was determined to ontologically fit the definition for a dashboard and contained information specific to COVID-19 disease proliferation or vaccine distribution, I recorded its URL and the name of the country it was associated with in a spreadsheet to revisit during my content coding.

Coding Scheme Creation

Once the dashboards were identified, I developed a set of *codes*, or questions about a dashboard’s characteristics, which accounted for: 1) metadata about the URL and country name, 2) if the webpage had been archived, 3) the metadata available on the dashboard, 4) the data display types in the dashboard, 5) the dashboard layout, 6) dashboard interaction, 7) use of color as a visual variable, and 8) questions regarding data download options and language localization that related to my research questions. A comprehensive list of the dashboard codes, which total

46 individual characteristics, can be found in *Table 1*. These allowed for a comprehensive review of dashboard content and compositional patterns.

Codes 1-3, were regarding general information about the dashboard, including the country name, a unique identifier for the dashboard, and the dashboard's URL. Codes 3-6 pertain to if the dashboard can be archived on the WayBack Machine and where the URLs for archived dashboards exist. I chose to included a dashboard as archived if it was able to 1) successfully load and 2) most of the widgets were viewable. Codes 7-43 were adapted from Bach *et al.*'s 2022 article, which defines typologies of dashboard layout. Of those questions, codes 7-11 were related to metadata availability. Codes 12-23 were what Bach *et al.* refers to as *visual representation patterns*, or the ways that data can be laid out on a page. In these questions, the only time where I significantly deviated from Bach *et al.'s* typologies was because many of the dashboards included or featured maps, which were not one of the visual representation patterns that Bach *et al.* identify. Codes 29-34 refer to how the widgets within a dashboard get configured on a webpage. Codes 35-38 refer to how a user can interact with the dashboard to gain new insights from the data, and codes 39-42 pertain to how color gets used as a visual variable in a dashboard. Codes 43 and 44 are based on common strategies for COVID-19 communication I saw in my literature review and are my opportunity to assess the connection between COVID tracking apps and communicating modeled projections of future disease spread. Code 45 is about the platform that the software was built in. Finally, coding question 46 relates to the ability of the user to download and access the data underlying the platform. Although some dashboards had "data download" buttons built into the dashboard, many contained links to external data platforms or APIs, so the diversity of these options are captured in multiple choice answers.

The majority of the codes were derived from Bach et al.'s taxonomy of dashboard design elements, however, Bach *et al*'s article does not specify any cartographic elements in a dashboard, so I additionally coded for the presence or absence of maps in data display patterns. Additionally, I coded for if the dashboard included any future forecasts of COVID-19 progression, if the dashboard was archivable on the WayBack Machine, if the dashboard linked to an external mobile application, what platform the dashboard was designed in, and if there were opportunities to download the data. All of the codes (except where noted in *Table 1*) were designed as a Boolean "yes" or "no" with an opportunity to flag it for review later. Coding the maps as a Boolean value made it easier to assess the presence or absence of each feature and allowed me to apply simple arithmetic to interpret the results.

Table 1: Detailed description of all coding questions in the content analysis

Feature Examined	**Question**	**Data Type**	**Question Source**
General information	What is the country name?	Text	General Metadata
	What is the dashboard ID? (ISO code + dashboard number for the country, ex. US1)	Text	General Metadata
	What is a link to the dashboard?	URL	General Metadata
Archivability	Is the dashboard viewable on the Way Back Machine? https://archive.org/web/	Boolean	Research Question 2
	Link to Way Back Machine archive of dashboard:	URL	Research Question 2
	Date of Way Back Machine capture, closest to September 1st	Date	Research Question 2
Metadata and data explanations	Does the dashboard list data sources?	Boolean	Adapted from Bach *et al.*
	Does the dashboard list data disclaimers about data processing or context?	Boolean	Adapted from Bach *et al.*

	Does the dashboard include data descriptions about what the user is seeing?	Boolean	Adapted from Bach *et al.*
	Does the dashboard include update information including timestamps	Boolean	Adapted from Bach *et al.*
	Does the dashboard include annotations to the graphs which add insight into the data?	Boolean	Adapted from Bach *et al.*
Visual representation patterns	Does the dashboard have tables to display data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard have lists to display data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard have detailed charts that let the user retrieve specific values from the data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard have miniature charts that let the user generalize trends from the data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard have gauges or progress bars to display data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard have pictograms to display data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard use trend arrows to display data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard use numbers (alone, not annotating another data display) to display data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard use maps to display data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard include a choropleth map?	Boolean	Added to Bach *et al.*'s typologies based on observation
	Does the dashboard include a graduated symbol map?	Boolean	Added to Bach *et al.*'s typologies based on observation
	Does the dashboard include any other maps besides choropleth or graduated symbol?	Boolean	Added to Bach *et al.*'s typologies based on observation
Dashboard layout patterns	Did the dashboard use an open layout without specific rules for widget placement?	Boolean	Adapted from Bach *et al.*

	Did the dashboard use a stratified layout with a top-down ordering, where top-level information is emphasized?	Boolean	Adapted from Bach *et al.*
	Did the dashboard use a table layout and order the dashboard into meaningful columns and rows?	Boolean	Adapted from Bach *et al.*
	Did the dashboard use a grouped layout and order the dashboard into meaningful groups by theme?	Boolean	Adapted from Bach *et al.*
	Did the dashboard use a schematic layout?	Boolean	Adapted from Bach *et al.*
Screen space patterns	Does the dashboard use screenfit, fitting all the content into a page without the need to scroll or interact with data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard use overflow, where the data exceeds the website length and scrolling is required to explore all the data?	Boolean	Adapted from Bach *et al.*
	Does the dashboard use details on demand to allow the user to show more details through interaction?	Boolean	Adapted from Bach *et al.*
	Does the dashboard use parameterization to allow the user to show more details that ae customized to their interests?	Boolean	Adapted from Bach *et al.*
	Does the dashboard use multiple pages where content was split across multiple pages or tabs with navigational patterns?	Boolean	Adapted from Bach *et al.*
	Does the dashboard encourage users to visit an external (non-governmental) website to access more information?	Boolean	Added to Bach *et al.*'s typologies based on observation
Dashboard interaction	Does the dashboard allow the user to explore the data, obtain new data, and explore relationships through exploration interaction?	Boolean	Adapted from Bach *et al.*
	Does the dashboard allow the user to focus on specific data through drilldown interaction?	Boolean	Adapted from Bach *et al.*
	Does the dashboard allow the user to tab between multiple pages through navigation interaction?	Boolean	Adapted from Bach *et al.*
	Does the dashboard allow the user to redefine, filter, and reconfigure data through personalization interaction?	Boolean	Adapted from Bach *et al.*
Supplementary feature	Does the dashboard recommend downloading an external mobile application?	Boolean	Research Question 2

Supplementary feature	Were forecasts of future disease spread included in the dashboard?	Boolean	Research Question 2
General information	What GUI/JS Library was the dashboard built in?	Multiple choice	General Metadata
Supplementary feature	Are there options to download the data?	Multiple choice	Research Question 2

Coding Dashboards

To code each dashboard across all of the codes, I developed a form in Microsoft Forms using the questions listed in *Table 1*. For each dashboard I had selected, I entered the URL of the dashboard into my Google Chrome web browser. Since the coding sheet was input into Microsoft Forms, it was easy for me to make sure I coded for the presence or absence of each characteristic. I included a third option on all questions to allow myself to flag a feature for review. Later, after I had coded all the dashboards, I went back and revisited all of the flagged features. In this stage, I revisited Bach *et al.'s* paper and my literature review for the criteria for each question and then I decided on the most appropriate option for that feature.

Analysis

Once my coding was complete, I exported a spreadsheet from the Microsoft Forms site. Most of my codes were boolean, which allowed for simple arithmetic and filtering across the dataset. For each characteristic, the values were summed in the spreadsheet. I used the counts to answer the broader research questions posed in the introductory chapter.

Archiving

As I was working through coding the COVID-19 dashboards in Spring 2023, I noticed that many of the dashboards were slowly being removed from the Internet as the global community moved away from more active strategies for COVID-19 containment. While in the initial "Identifying Dashboards" stage, I recorded the URLs for dashboards to be able to easily return to the webpages. However, in several instances I found the URL path to be broken.

I attempted to find the dashboards through the web archiving platform called the WayBack Machine. The WayBack Machine allows users to save webpages and archive them for the future ("Using the WayBack Machine"). However, in the case of COVID-19 dashboards, I found that in many cases the dashboards were not usable or accessible through the archive. Webpages often rely on many layers, often referred to as a "tech-stack," interacting together as scaffolding for the website as it appears in our browsers. The WayBack machine is most efficient at capturing HTML—the "backbone" language in web programming—and struggles with capturing data stored on remote servers or which relies heavily on JavaScript ("Using the WayBack Machine") such as web maps and data dashboards. This meant that in the case of analyzing COVID-19 dashboards, these webpages were not captured in the Wayback Machine effectively. The ability to capture and later re-create the content, structure, functionality, and front-end presentation of a website is known as *archivability* (Stanford Libraries, "Archivability").

To retain a record of all dashboards, even the ones that were not archivable, I systematically went back through each dashboard and recorded myself interacting with each dashboard after I coded its content. For dashboards organized in a linear manor (such as France), where it was straightforward to scroll through all the screen length and pages in the dashboard, I recorded the dashboard and all related features. For larger dashboards (such as the United States), which spans dozens of pages and/or has interactive features in a non-linear fashion, I focused on recording one exemplar of each data visualization element (i.*e.* capturing at least one detailed bar chart at one choropleth map). I have uploaded the recordings to https://github.com/LucyMakesMoreMaps/COVID_Dashboards. This repository is freely available for the public to view and is available under the Creative Commons license CC BY-SA. In archiving these records, I hope to provide a resource for public health communications experts to evaluate the global response to COVID-19 so we can learn from past lessons and apply them to future emergency situations.

Chapter 4: Results

Across the 45 countries I searched for dashboards for, I was able to identify 28 dashboards that fit my definition of a dashboard. After identifying those 28 dashboards, I went back to code each dashboard. Several (n = 4) had been removed from the internet and were no longer accessible. In total, I was able to code for 24 international COVID-19 dashboards. Among those 24 coded dashboards, there was a wide variety of designs and ways in which data was made available. This chapter provides the results from my content analysis, as they relate to Research Questions 1 and 2, which informs the user stories outlined in "Chapter 6: Discussion."

Identified Dashboards

Among the 24 dashboards I did code for, 22 of the dashboards followed standard definitions for dashboard design and functionality. The two cases that did not follow the strictest definitions of a "dashboard," were created by Romania and China, and were still included in my analysis because they provided regularly updated data in a curated format to their citizens. Romania's dashboard, pictured in *Figure 2,* did not include interactive elements, instead, the central webpage linked to a series of PDFs with regularly updated visualizations of COVID-19 spread and vaccination rates. Other research has categorized these sites which provide regularly published PDFs as dashboards (Wexler *et al.* 2022).

Figure 2: Screenshot of Romania's dashboard

China's dashboard on the other hand, *Figure 3*, was a list of regularly updated announcements about the state of the pandemic and vaccination initiatives across China. Although the Chinese COVID information website did not include visualizations as might traditionally be considered a dashboard, I included it in this study for the following reasons. First, other researchers have defined China's COVID-19 information website as a dashboard (Zhao *et al.* 2021). Second, the decision to convey data through written text without any visual support or external data sources is, in and of itself, a purposeful lens through which Chinese COVID-19 data is conveyed. Finally, China's COVID response was relevant to how countries across the globe responded given that the COVID-19 pandemic started in Wuhan, China, thus capturing their dashboard helps provide a picture of the diversity of data communication styles.

Figure 3: Screenshot of China's COVID-19 dashboard in Chinese (top) and translated into English using Google Translate (bottom)

Throughout the rest of this chapter, I specifically illustrate how my data answered the research questions I posed at the outset of this thesis.

Research Question 1

How did COVID-19 dashboards created by national government organizations differ in their design?

Metadata and data explanations

Of the 24 dashboards analyzed, most (*n* = 22) contained some kind of metadata about \the source of the data. The two dashboards that did not include any type of metadata or source were South Africa and Kuwait. Of the 22 dashboards that contained descriptions of the data and/or data sources, the breakdown of how many dashboards have what kinds of information are summarized in *Table 2.* Notably, none of these metadata and data descriptions are mutually exclusive, meaning a dashboard could be counted multiple times across the codes listed in Table 2. In my analysis, the most common type of metadata was "update information" such as timestamps (*n* = 20), where the dashboard included the last time the data were updated. For example, in Qatar's dashboard, *Figure 4,* the dashboard did not include any information about the data source except for the last time the data were updated.

Metadata and Data Descriptions	**Total**
Dashboard lists data sources	15
Dashboard lists disclaimers about data processing or context?	13
Dashboard includes descriptions about what the user sees	5

Dashboard includes update information, such as timestamps	20
Dashboard includes annotations to the graphs which add insight into the data?	3

Table 2: A summary of content analysis results regarding dashboard update information

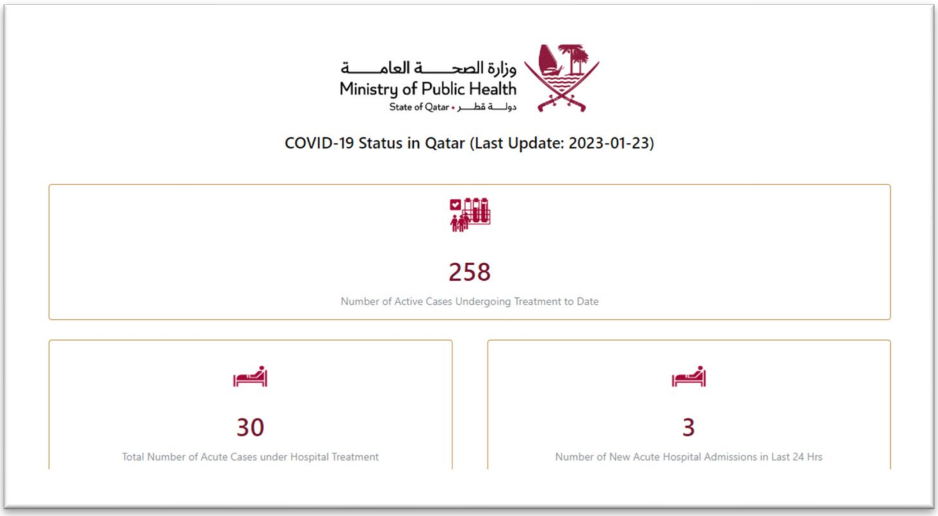


Figure 4: Qatar's dashboard included a timestamp of the last time the data updated

The second most common type of metadata were simply explicite "lists of data sources" (*n* = 15). "Disclaimers" about data processing or important context were the next most common (*n* = 13). For example, Indonesia's dashboard (*Figure 5)* prominently features a disclaimer in bright teal at the bottom of their dashboard.

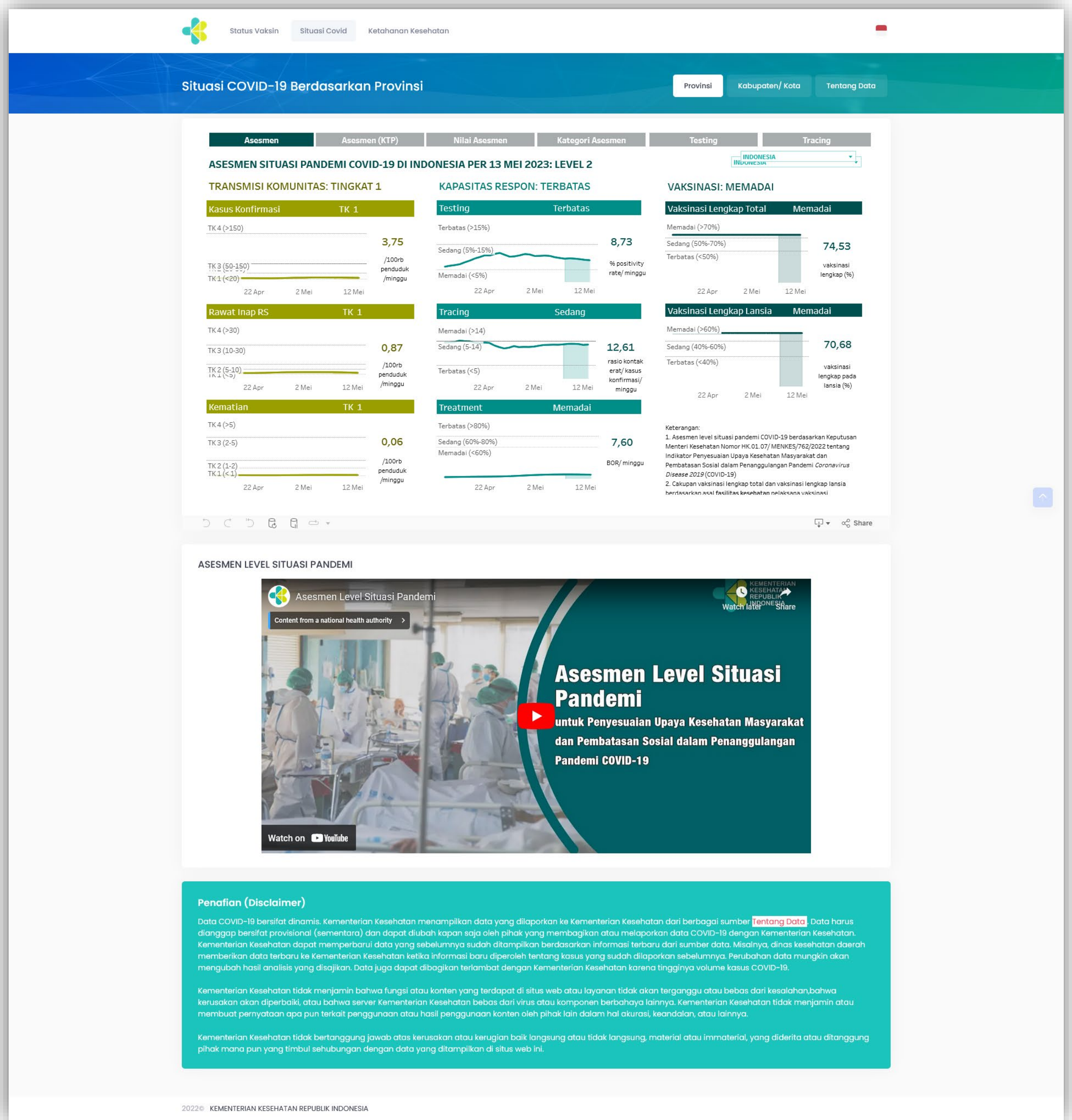


Figure 5: Indonesia's dashboard shows a prominent data processing disclaimer.

Very few dashboards "described the data" through a description of what the user sees ($n = 5$). "Annotations to the graphs" to add insight into the data ($n = 3$) were the least common form of metadata or data explanation. For example, in France's dashboard, *Figure 6,* a red or green arrow summarizes if the data is trending up or down in the last 7 days through an annotation to the graphs which add insight into the data.

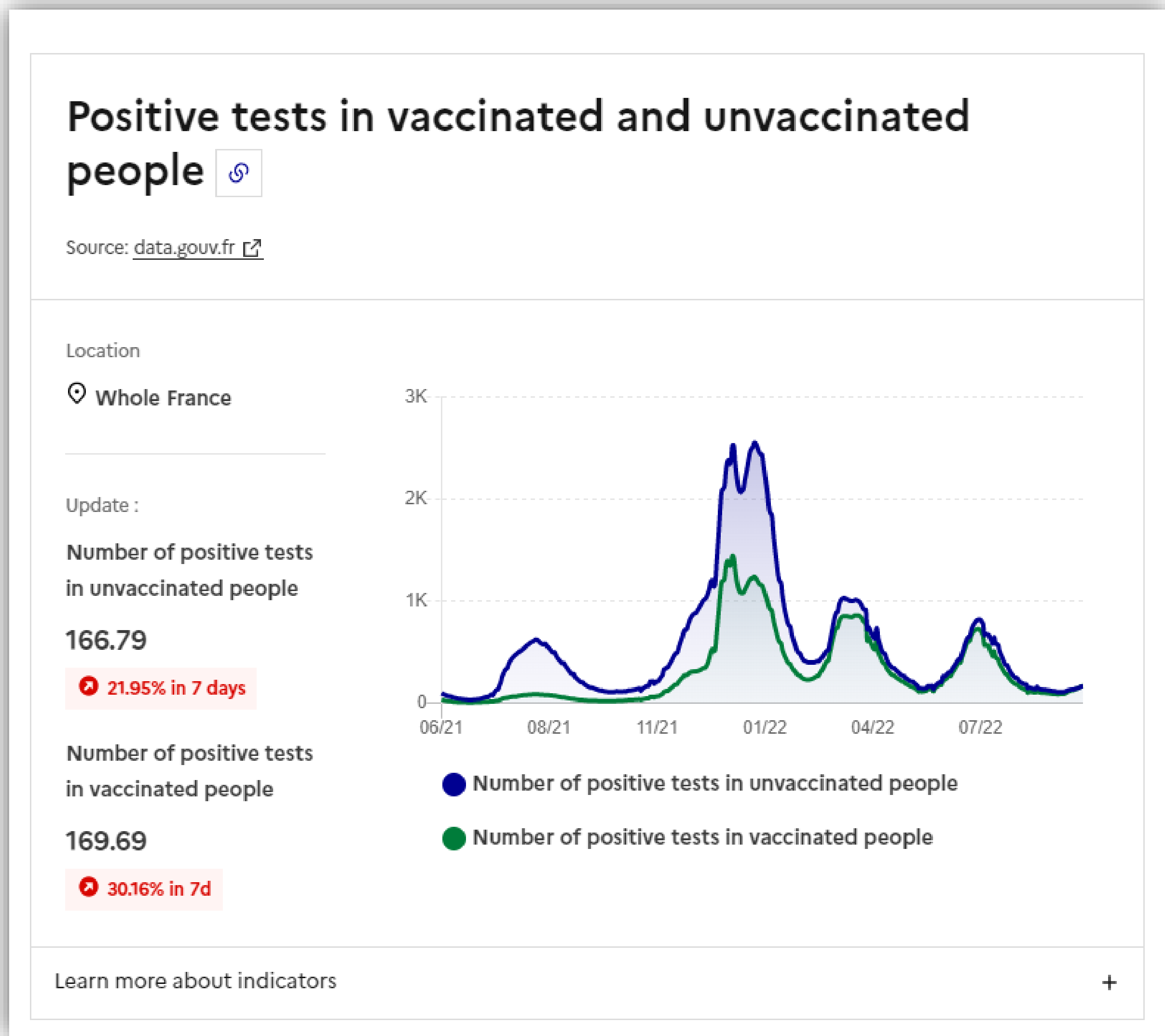


Figure 6: France's dashboard includes indicators of how the data are trending and descriptions of how the data are calculated.

Visual representation patterns

The visual representation pattern codes in my coding scheme were based on Bach *et al*. (2022), with four additional questions focused on map design since Bach *et al.* (2022) did not include maps in their taxonomy of dashboards, despite that I found maps to be a common visualization across the dashboards I coded (see *Table 3)*.

Visual Representation Pattern	**Total**
Tables	15
Lists	3
Detailed charts with specific data points	19
Miniature charts with generalized trends	4
Gauges or progress bars	4
Pictograms	0
Trend arrows	6
Numbers (alone)	20
Map, general	15
Choropleth maps	14
Graduated symbol maps	4
Other maps	2

Table 3: A summary of the visual representation patterns in the analyzed dashboards

The most common visual representations were: “numbers” (n = 20), “detailed charts with specific data points” (n = 19), “tables” (n = 15), and “maps” (n = 15). Again, these codes are not mutually exclusive, thus a dashboard could contain all these types of visual representations, or none. Additionally, these counts illustrate the number of dashboards that contained that visual representation type, not the number of times I observed that pattern displayed. For example, France had a long list of detailed charts (See, for example, *Figure* 6) but is represented just once in the count of "detailed charts with specific data points." The least commonly used visual representation patterns were "gauges or progress bars" (*n* = 4), "miniature charts with generalized trends" (*n* = 4), "lists" (*n* = 3), and "pictograms" (*n* = 0).

Of the 24 dashboards analyzed, over half (*n* = 15). Of the 15 dashboards which included maps, "choropleth maps" (e.g., *Figure 7)* where the color of enumeration units within the map are shaded according to the data value, were the most common (*n* = 14), followed by "graduated symbol maps" (e.g., *Figure 8),* where the size of a given symbol is scaled based on the magnitude of the data value (*n* = 4). Bangladesh had the only dashboard (*n* = 1) which included a locator map. This map included locations for COVID care clinics and vaccination site shown in *Figure 9*. Pakistan included the only dashboard which featured an administrative map which was annotated with the numbers of cases in each administrative unit, but the units were not colored based on any variable (*Figure 10*).

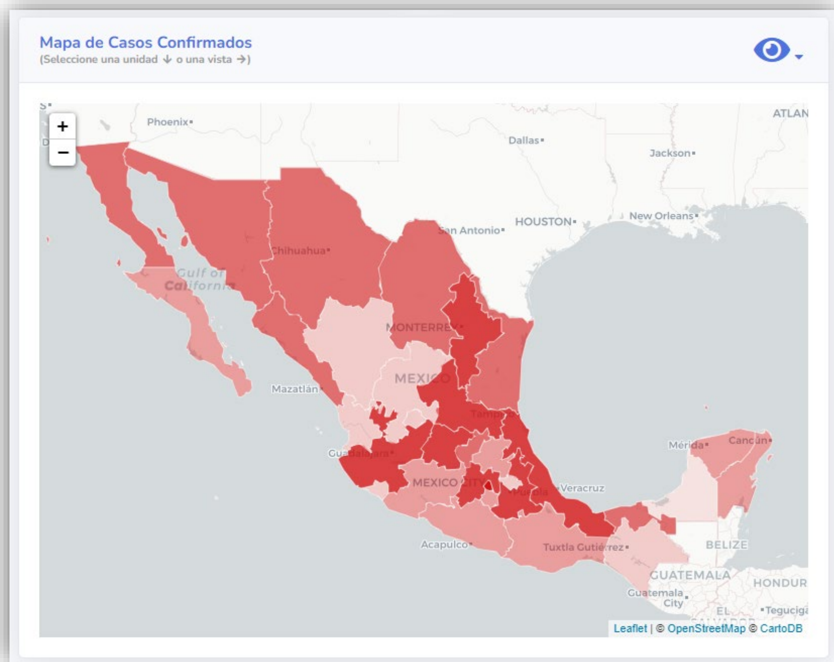


Figure 7: Mexico used a choropleth map to show confirmed COVID cases

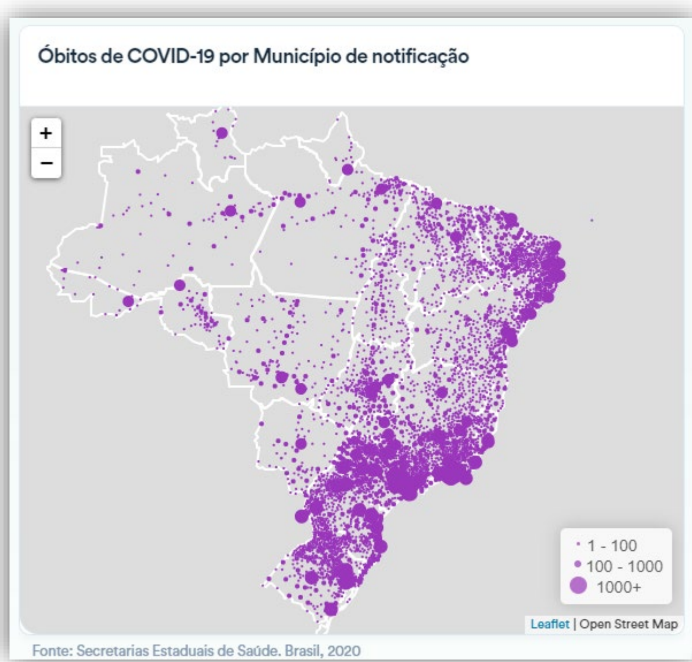


Figure 8: Brazil uses a graduated symbol map to show COVID-19 deaths

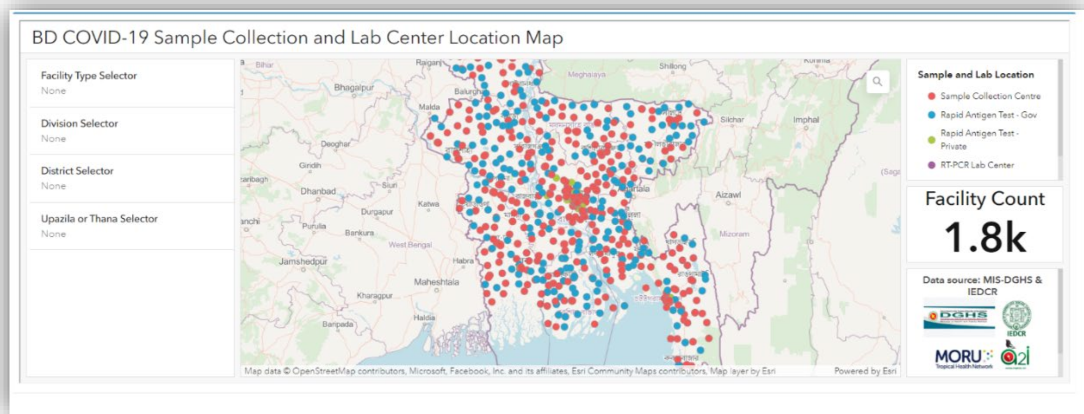


Figure 9: A categorical map of COVID-19 testing centers in Bangladesh

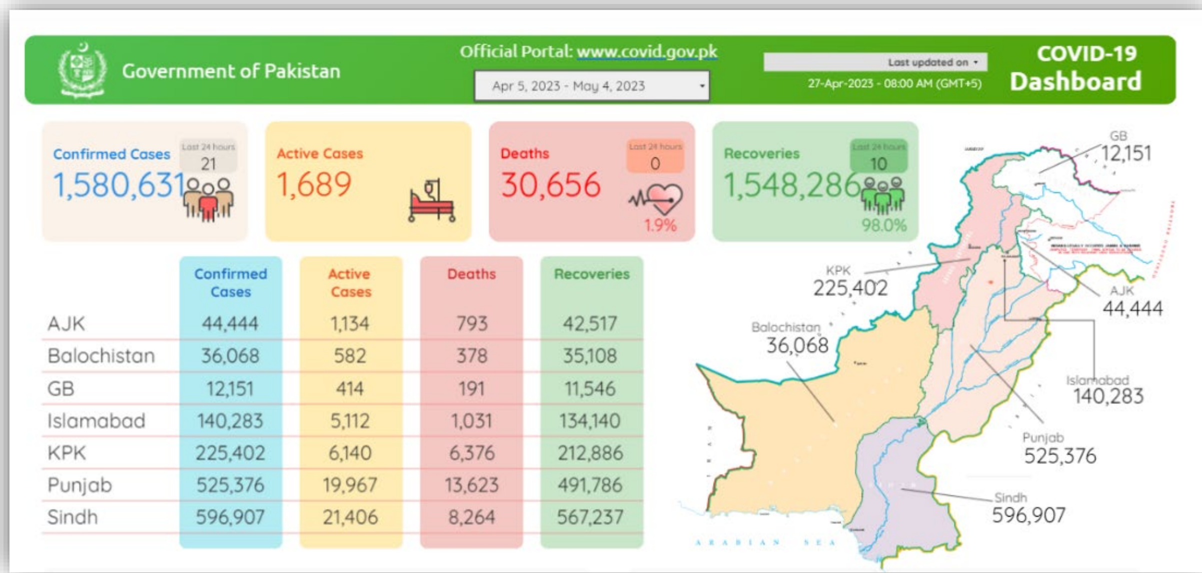


Figure 10: Annotated administrative map from Pakistan's dashboard

Dashboard Layout Patterns

I coded for dashboard layouts, also using Bach *et al.*'s typology. The results are summarized in *Table 4.*

Layout Types	**Total**
Open Layout	11
Stratified layout	9
Table layout	7
Grouped layout	5
Schematic layout	0

Table 4: A summary of dashboard layout patterns identified in the content analysis

Among the dashboards I analyzed, "open layouts" were the most common (*n* = 11). Argentina's dashboard, pictured in *Figure 11,* is a good example of an "open layout," where the ordering of the widgets on the page does not correspond to the content or importance of the widget provided. "Stratified layouts," where the widgets were ordered so that the most succinct and important information was at the top were the second most common (n = 9). Mexico's dashboard (*Figure 12*) is a neatly organized example of a dashboard with a stratified layout. "Table layouts," where the content was arranged into meaningful columns and rows (*n* = 7) were also relatively common, as pictured in Qatar's dashboard in *Figure 13*. In the dashboards I analyzed, I identified 5 which used "grouped layouts," where the widgets are laid out in clusters of related data. For example, in Saudi Arabia's dashboard, *Figure 14*, widgets related to cumulative and current COVID-19 cases are grouped together and widgets related to vaccination statistics are grouped together. "Schematic layouts" use the layout of widgets to convey information about the structure of the data. I did not find any examples of a schematic layout for COVID-19 dashboards.

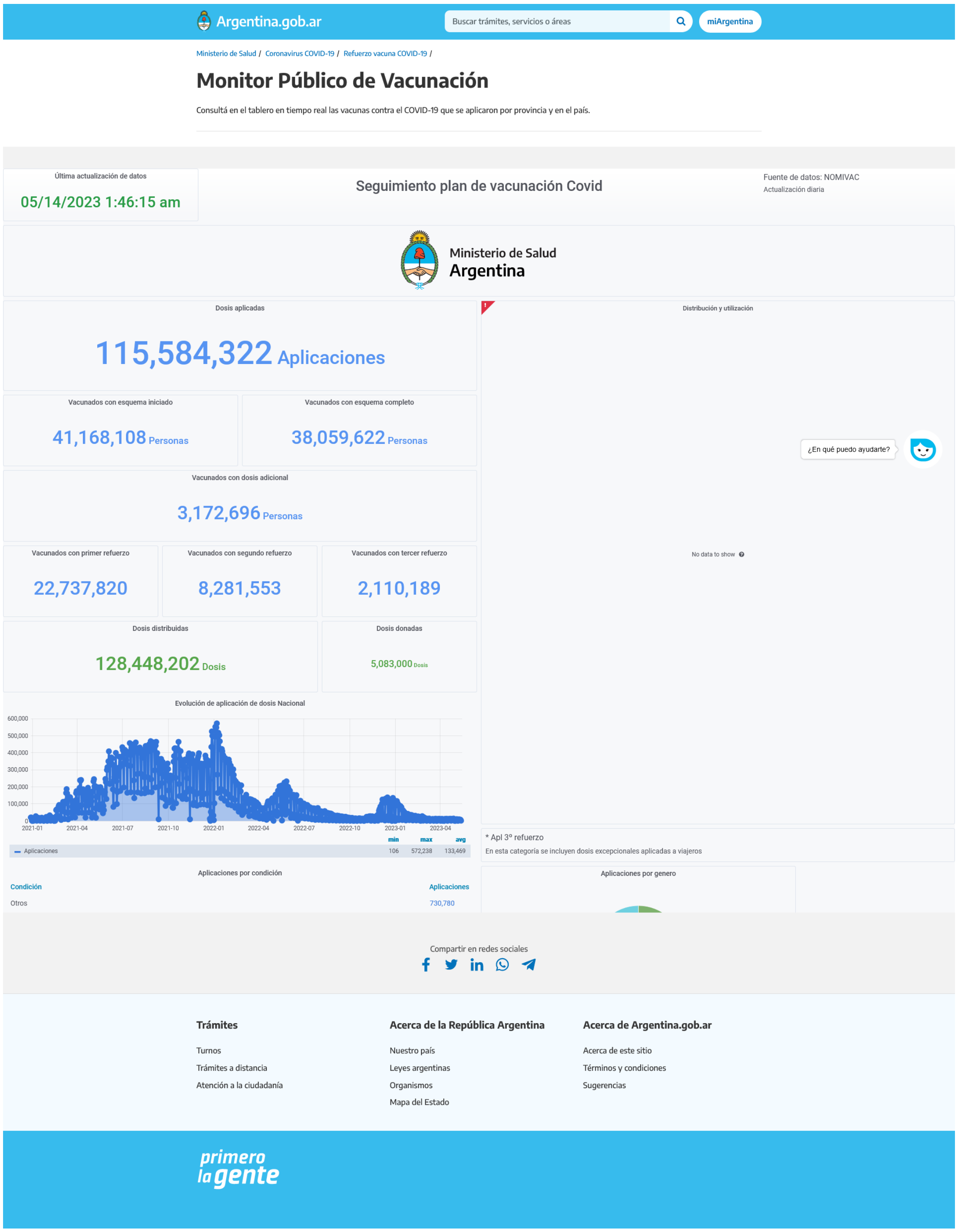


Figure 11: Argentina’s dashboard uses an open layout

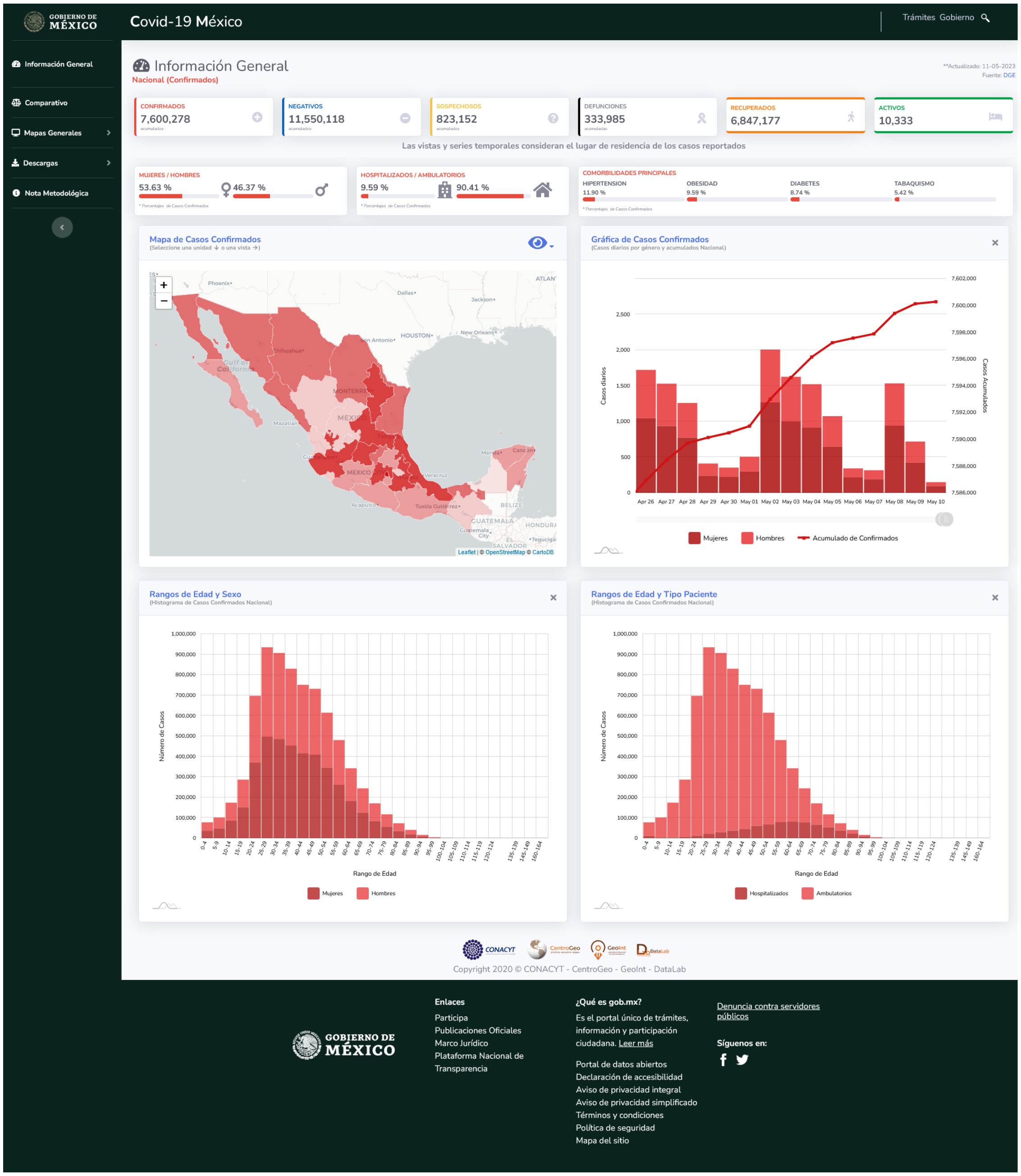


Figure 12: Mexico's dashboard is a stratified layout, with the most important information aligned along the top of the webpage.

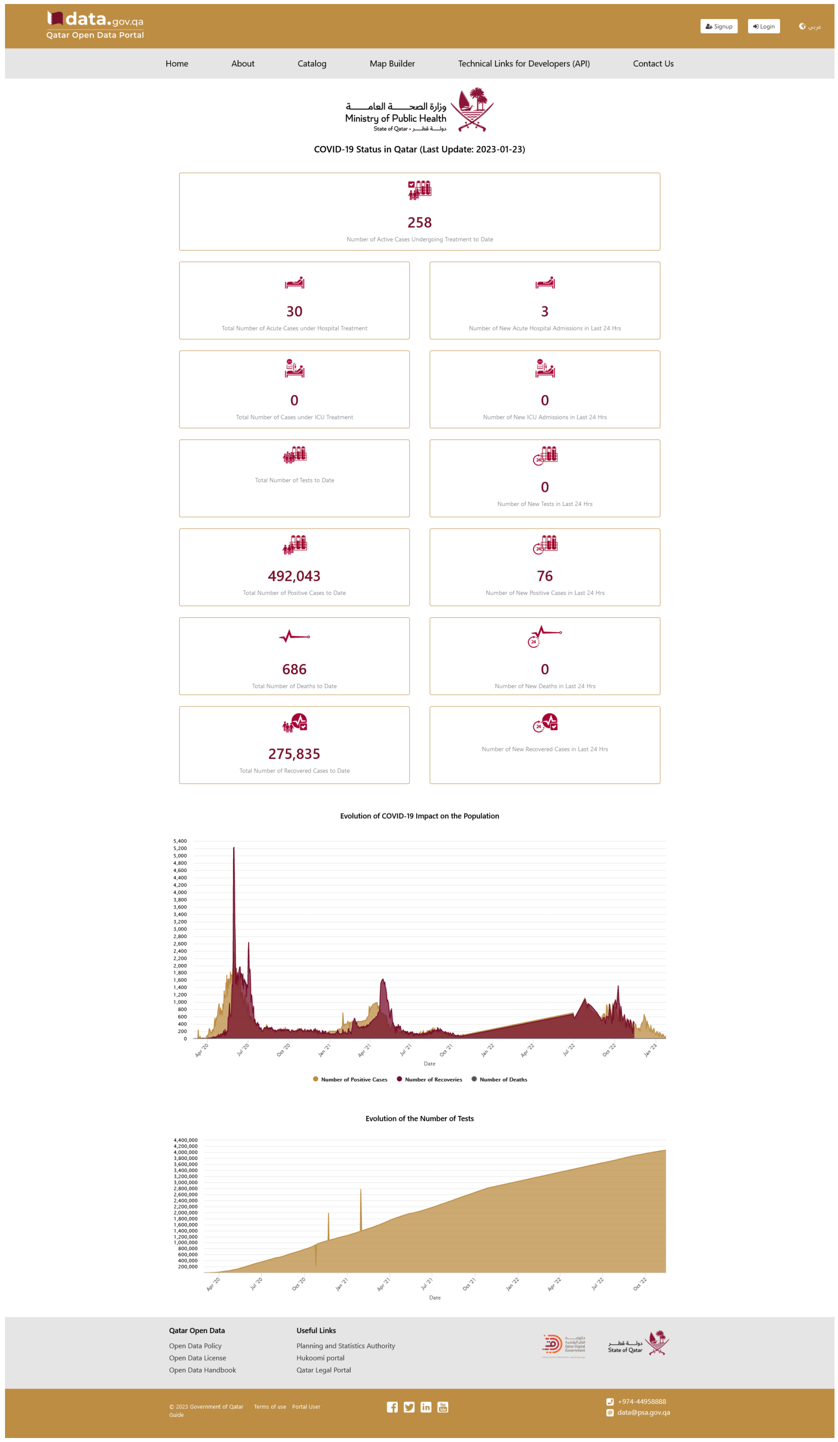


Figure 13: Qatar’s dashboard arranged data into meaningful rows and columns

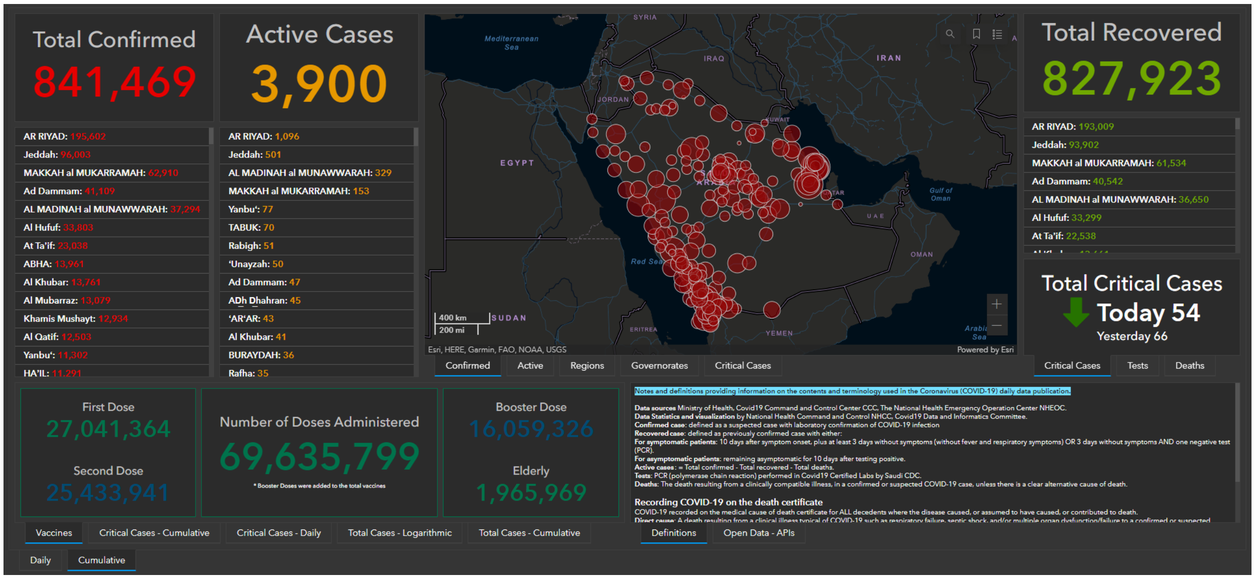


Figure 14: Saudi Arabia's dashboard clustered similar data together using a grouped layout

Screen Space Patterns

Although early dashboards were often designed as a static dashboard and viewed on a single screen, the proliferation of dashboards online has resulted in the expansion of dashboard forms into dynamic visualizations which take up significant screen space. I use Bach *et al.*'s typologies for screen space patterns. My analysis, summarized in *Table 5,* finds that the most common patterns are "overflow," where the user has to scroll to see all the content (n = 18) and the use of "multiple pages" with linked navigational patterns (n = 14). The least commonly used screen space patterns were "screenfit," where the data all fit into one screen without interaction (n = 4) and "details on demand," where the user has to expand an element to get more information (n = 5).

Fitting patterns	**Total**
Screenfit	4
Overflow	18
Details on demand	5
Parameterization	8
Multiple pages	14
Link to external site	6

Table 5: A summary of dashboard screen space patterns identified in the content analysis

Dashboard interaction

Dashboard interaction encompasses the ways that a dashboard allows a user to interact with and explore data. In my analysis, summarized in *Table 6*, the most common types of interaction were "comparative interaction," where the user could toggle between multiple tabs or pages to compare data (n = 13) and "drilldown interaction," that allowed the user to focus on specific data (n = 11). "Exploration interaction" to allow users to explore data or obtain new data was significantly less common (n = 5), as were "personalization interactions" that allow the user to redefine, filter, or reconfigure data to personalize the dashboard to their interests (n = 4). The more common dashboard interaction patterns were also the patterns that allow dashboard designers to have the most control over the narratives in each dashboard.

Dashboard interaction patterns	**Total**
Does the dashboard allow the user to explore the data, obtain new data, and explore relationships through exploration interaction?	5
Does the dashboard allow the user to focus on specific data through drilldown interaction?	11
Does the dashboard allow the user to tab between multiple pages through navigation interaction?	13
Does the dashboard allow the user to redefine, filter, and reconfigure data through personalization interaction?	4

Table 6: A summary of dashboard interaction patterns identified in the content analysis

Modeling Future Disease Spread

Among the dashboards I analyzed, the United States developed the only dashboard (n = 1) which contained any data modeling future progression of COVID-19 spread. All other dashboards (n = 23) were focused on the current status of the proliferation of and vaccination against COVID-19.

Research Question 2

> How did national COVID-19 dashboards differ in the functionality for data download, language localization, and archivability? What impact did Platform as a Service (PaaS) providers have on the differences in functions between different countries' COVID-19 dashboards?

Platform as a Service Providers

Among the dashboards I analyzed, a wide variety of platforms were used to build the dashboards. Of the 24 total dashboards, 3 were built using Esri's Dashboard Builder, 3 were built using Microsoft's Power BI, 2 were designed in Google's Looker Studio, and 2 were definitively designed in Tableau. One dashboard (*Figure 13*, Bangladesh) was built without using a PaaS, but included a included a single widget (outlined in red at the bottom of the page) within the overall dashboard layout which was built using Esri's ArcGIS Dashboard Builder. For the purposes of this thesis, I did not include this dashboard in the overall count of Esri dashboards because the widget was a singular feature in the overall dashboard. While I only identified 2 dashboards in my study set which were designed in Tableau, Tableau was the only PaaS provider that allowed users to remove their "watermark," the icon or logo of the company, depending on the subscription level paid for by the dashboard developer. This meant that countries who paid for a higher license level had the option to remove the watermark. Additionally, I could not find any third-party tools (such as Wappalyzer) that would help me to identify when Tableau was present in each website's technology stack, so there was no accurate way to identify whether a dashboard was made with their platform without the watermark. Together, this meant I was not able to identify what tools were used for 11 of the remaining dashboards. Therefore, it is possible that some of the dashboards were designed in Tableau that are unaccounted for in my final counts.

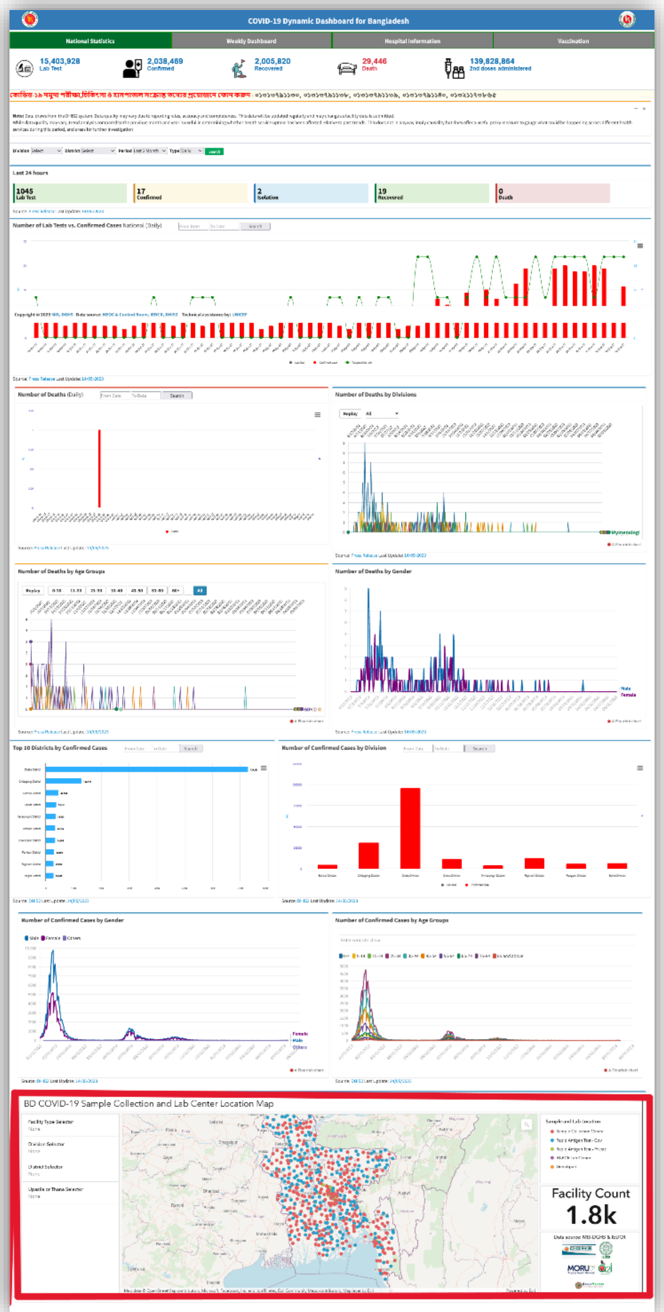


Figure 15: Bangladesh’s dashboard included one widget designed in Esri’s Dashboard Builder

Data Download Options

Among the dashboards I analyzed, some had options to download either an image of the dashboard or the data underlying the dashboard itself, summarized in *Table 7*.

	Built using a PaaS provider	Not built using a PaaS provider
Data download options made available	4/10	5/14
No data download options made available	6/10	9/14
Total % with data download options	40%	35%

Table 7: Data download options by platform the dashboard was designed on

However, among the dashboards that provided options to download data (*n* = 9), most did not integrate that data download into the dashboard itself; rather, they linked to an external database or API (*n* = 6). A breakdown of the types of data download options made available to users is summarized in *Table 8*.

	Built using a PaaS provider		Not built using a PaaS provider	
	Data download integrated	Link to external API	Data download integrated	Link to external API
Data download options made available	*n = 2*	*n = 2*	*n* = 1	*n* = 4

Table 8: Data download options broken down by how the data were made available

Language Localization

Of the 24 dashboards in the analysis, one third (*n* = 8) included options to toggle between one or more languages, known as *language localization*. Of those 8 dashboards, most (*n* = 7) allowed for toggling between two specific languages-- the local language of that country and English. For instance, the dashboard for India provided information in English and then also allowed users to toggle to Nepali (*Figure 16)*.

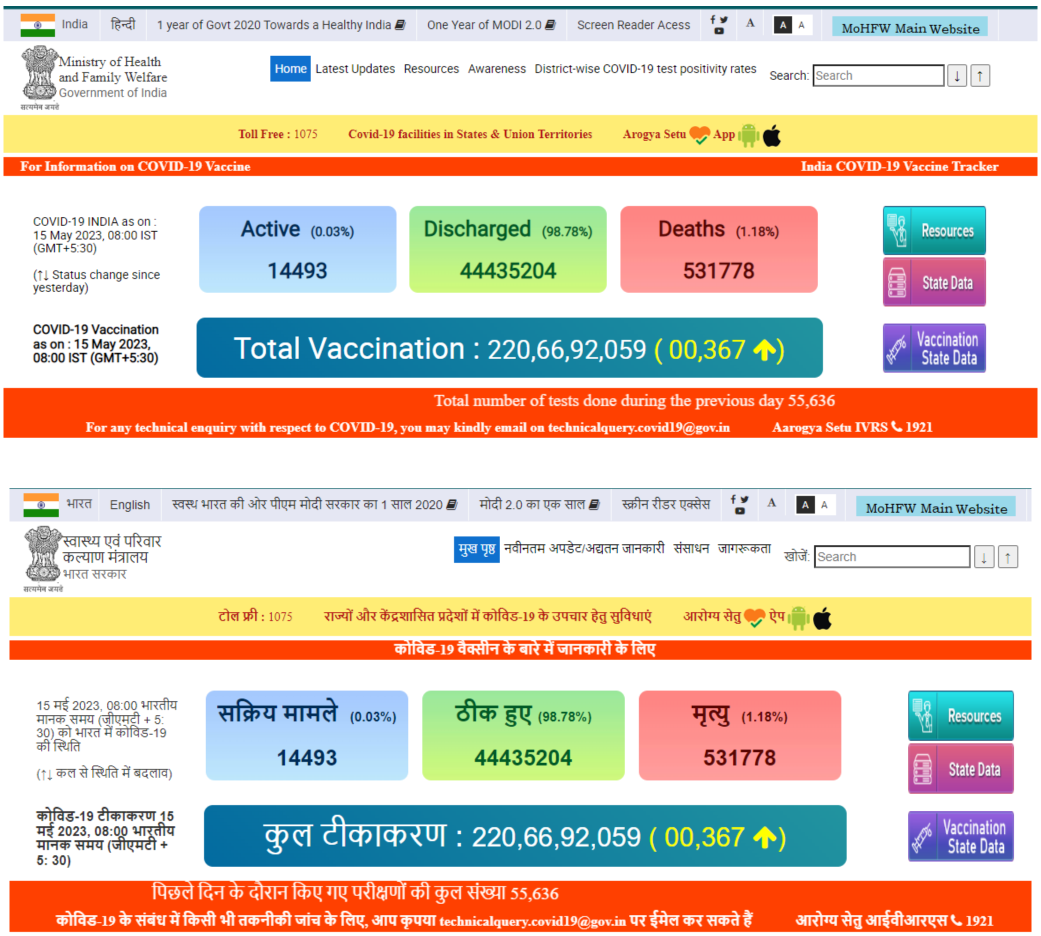


Figure 16: India's dashboard in English (top) and Nepali (bottom)

One dashboard (Egypt) allowed toggles between 24 languages with a wide range of alphabets. Notably, in the Egyptian dashboard, over half of the languages did not work and reverted the dashboard to English; however, there were about 11 languages which were still supported at the time of my analysis. Another small set of dashboards (*n* = 2, Belgium and Bangladesh) did not allow the user to toggle between languages but contained side-by-side information in multiple languages. As you can see in *Figure 17*, Belgium's dashboard was built in English, but has translations of the metadata into Dutch, French, and German.

Figure 17: The Belgian dashboard was built in English but had descriptions in 4 languages

Of the 8 dashboards with multi-language functionality, 3 of them were designed using a PaaS provider—one (Saudi Arabia) using Esri Dashboard Builder, and two (United States and Canada) using Microsoft Power BI. Notably, while Microsoft PowerBI has a localization engine and extensive documentation on how to localize a dashboard, Esri does not have language localization functionality. Saudi Arabia, the country that developed language localization using Esri Dashboards, had to build and maintain two separate dashboards and datasets, and changed which dashboard displayed for the user based on the user selected language.

Archivability

Determining the archivability of dashboards proved to be a challenge in this research. Some dashboards were accessible on web archiving platforms, but not all the widgets in each dashboard could be successfully rendered in the WayBack Machine. Qatar is a good example of a dashboard where all widgets are preserved and fully archivable. In *Figure 18,* you can compare the widgets available on Qatar's dashboard online compared with a capture from the WayBack Machine. In this image, all of the widgets are preserved and successfully loaded in the WayBack Machine, which means this dashboard is fully archivable.

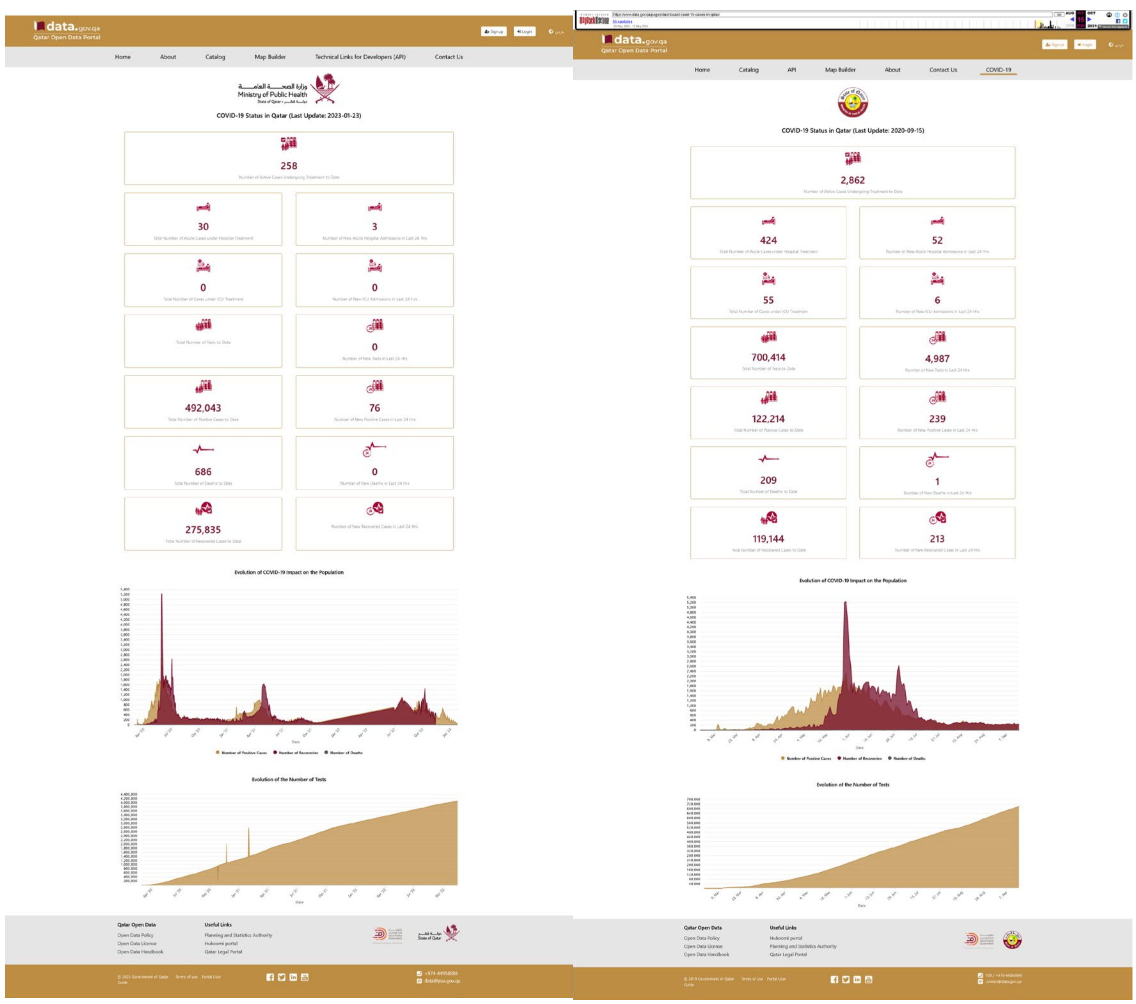
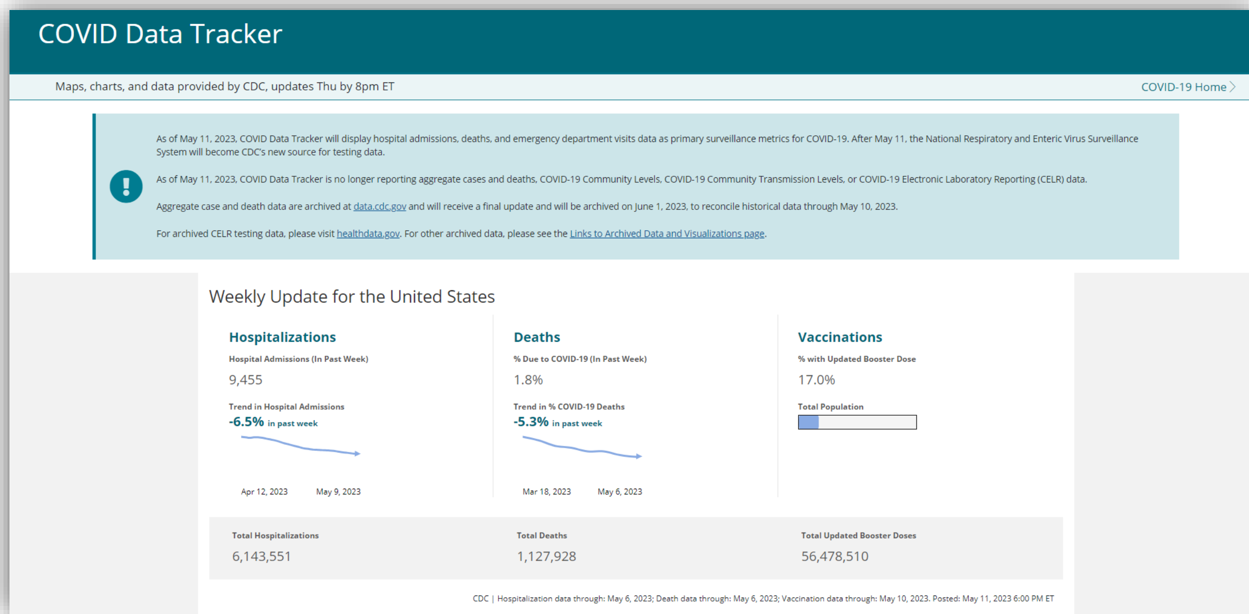


Figure 18: Qatar's dashboard online (left) compared with Qatar's dashboard in the WayBack Machine (right)



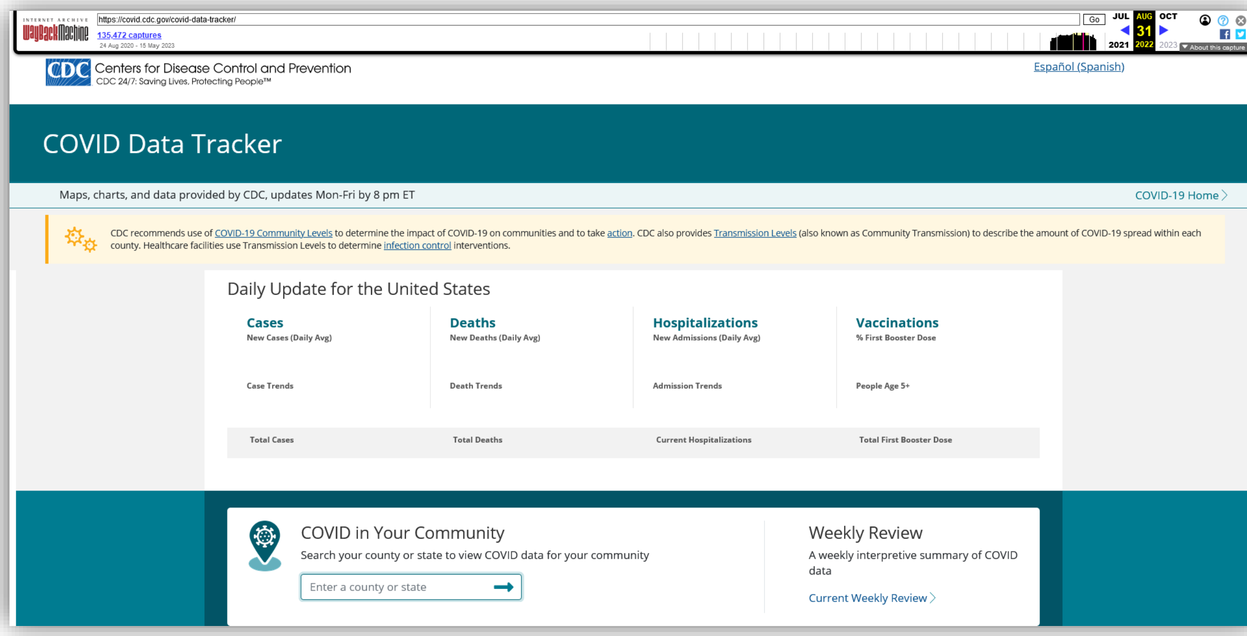


Figure 19: The United States’ COVID dashboard online (top) compared with the United States’s dashboard in the WayBack Machine (bottom)

Conversely, in *Figure* 19, you can see an example of a webpage that is mostly archivable. In the US COVID dashboard, the webpage and most of the information loads, but several of the data widgets are not rendered. Finally, in *Figure 20* you can see a non-archivable web map, where none of the data or content get loaded in the WayBack Machine. I chose to include a dashboard as archived if it was able to 1) successfully load and 2) most (more than 50%) of the widgets were viewable, meaning the dashboard was mostly archivable.

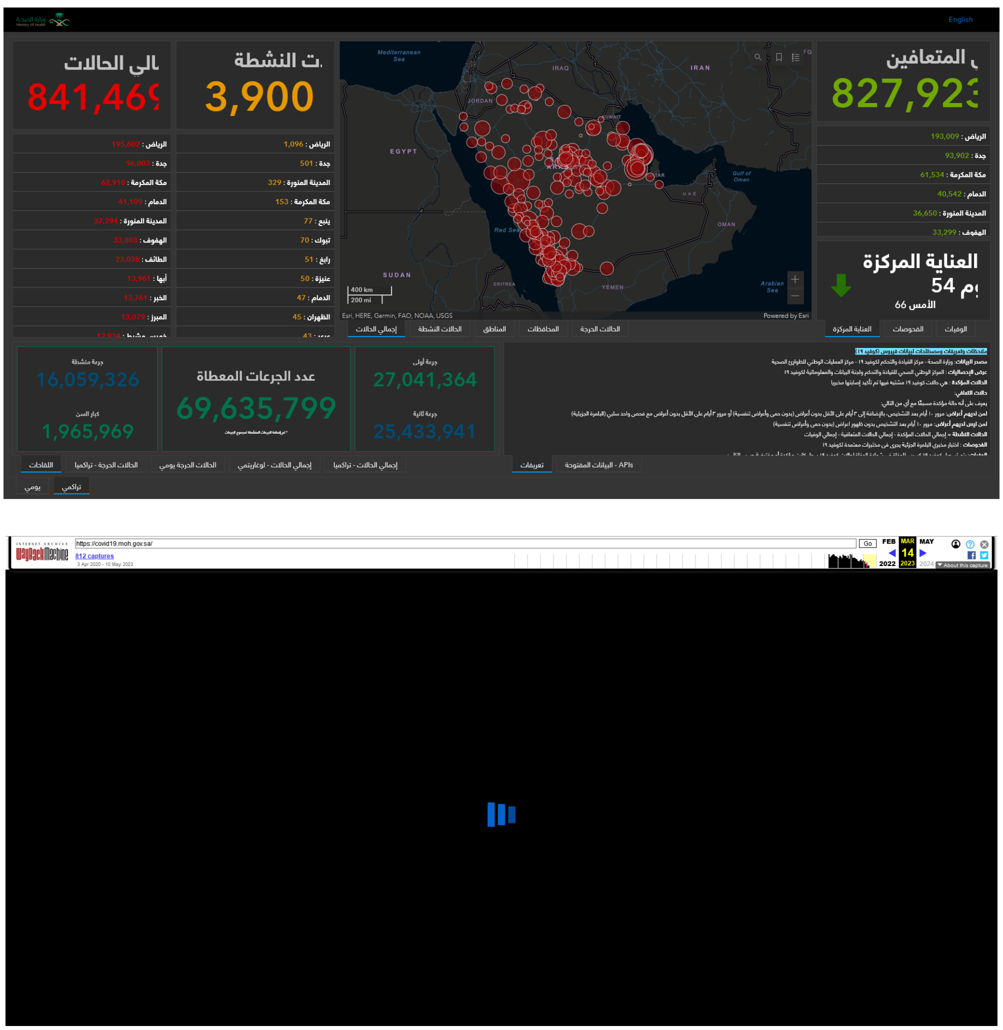


Figure 20: The Saudi dashboard online (top) compared to on the WayBack Machine (bottom)

The results of my coding for archivability are summarized in *Table 9.* 16 of the 24 dashboards that I identified were archivable, albeit to varying degrees, on the WayBack Machine. However, of the 16 archivable dashboards, the vast majority (*n* = 13) were built without a PaaS. Of the dashboards that were created with PaaS providers, dashboards that were built with Microsoft PowerBI and Tableau could be made accessible on the WayBack Machine. Notably, dashboards that incorporated widgets from Microsoft PowerBI were archivable, but dashboards developed entirely in the PowerBI app environment were not accessible through web archiving. Dashboards built in Esri Dashboard Builder or Google's Looker Studio also did not load on the WayBack Machine and were not archivable. Overall, 92% of the dashboards built without a PaaS were archivable on the WayBack Machine, while only 30% of the dashboards built with a PaaS were archivable.

	Built using a PaaS provider	Not built using a PaaS provider
Archivable	3/10	13/14
Not archivable	7/10	1/14
Total % Archivable	30%	92%

Table 9: Archivability of dashboards by the platform they were built on

Chapter 5: Discussion

Across the dashboards I analyzed, there was significant variation in how dashboards displayed data. This variation can be broadly divided into two categories—design patterns, driven by the person who was building the dashboard, and dashboard functionality, which was driven largely by the capabilities of the PaaS the dashboard was built on. The following section addresses each of the research questions, as they relate to the design and functionality of COVID-19 dashboards and highlights significant findings from my results.

Design Patterns

Dashboard Interaction Patterns

One notable pattern in the results was the dashboards' use of interaction (summarized in *Table 6*). Among the dashboards I analyzed, the most common interaction patterns were drilldown interaction — where the user can focus on specific data within the dataset — and navigation interaction — where the user can navigate between multiple pages or tabs and view new data. These two interaction patterns allow users to view the dashboard's data in more detail, but do not allow users to explore or reconfigure the data displayed.

The least common interaction patterns were personalization interaction — where the user can redefine, filter, and reconfigure the data to match their interests — and exploration interaction — where the user can explore the data and obtain new data to observe new relationships. Sarikaya *et al.* (2019) describe the differences in these dashboard interaction patterns as a tension between *visual dashboards*, which are simple data displayed with generic overviews of a dataset, and *functional dashboards,* which are interactive displays with real-time monitoring of many relevant variables. In a 2021 analysis of actionability in dashboard design, Ivankovik *et al.* determined that dashboards that manage the "type, quality, and flow" of data are more direct and actionable. In other words, they leave fewer decisions up to the user and provide clear guidance on how to take action based on the information provided. The prevalence of visual dashboards in my analysis indicate that globally, COVID-19 dashboards generally followed this paradigm and tried to moderate the type of information provided on their platforms.

Future Forecasts of Disease Spread

Of all the dashboards I observed, the United States had the only dashboard which modeled the potential future spread of the COVID-19 virus (*Figure 21*).

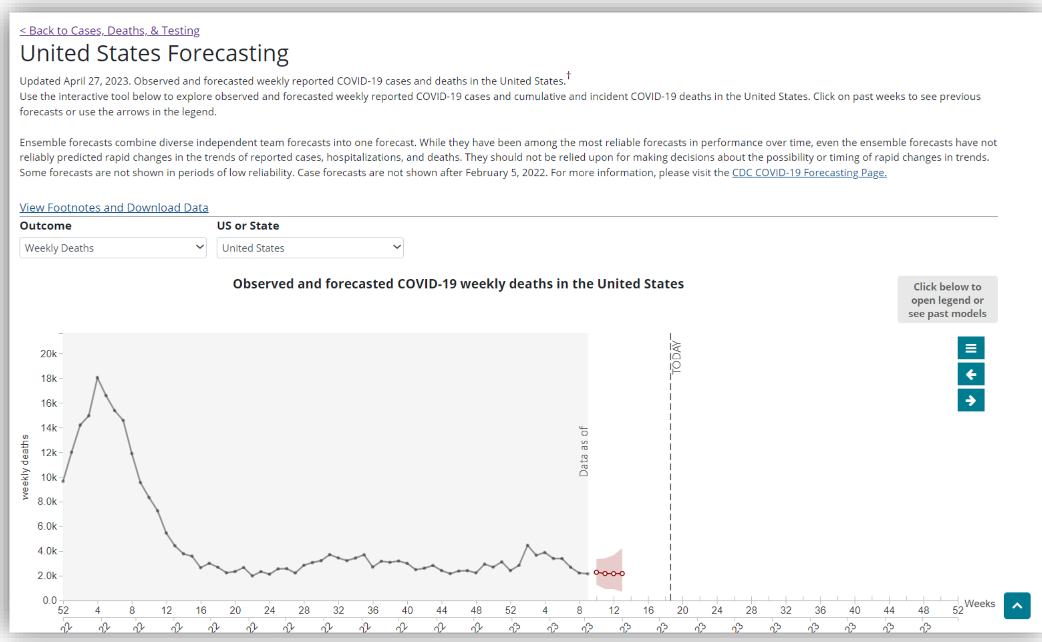


Figure 21: The US COVID dashboard forecasting future disease impact

This is notable, given Au *et al*.'s (2022) comparative analysis of expert narratives in COVID-19. They concluded that mainland China and Hong Kong were able create expert narratives around COVID-19 based on a shared cultural memory of the earlier SARS pandemic, which allowed for public health experts to create a cohesive narrative about how to collectively respond to the virus's spread. Meanwhile, the United States was unable to draw from any shared memory, and the political confusion that ensued in the United States in 2020 led the US CDC to share future projections to communicate the importance of protective measures (e.g. masking or social distancing). The fact that the United States was the only country to include future data models into their national dashboard confirms Au *et al.* that future modeling was a key part of US COVID communication strategy and further indicates that this communication strategy might have been unique to the United States.

Dashboard Functionality & User Stories

What was clear to me when analyzing COVID-19 dashboards was how significantly each dashboard was impacted and limited by the capabilities of the PaaS providers and their technology stack. Because drastically different governments, containment strategies, and disease rates all used just a few of these PaaS systems, it was clear that often the differences in the design, data availability, and functionality of individual country's dashboards were driven by the PaaS system they used more than it was an indication of differences in COVID-19 containment strategies. Therefore, given the need for these PaaS systems to allow for a greater diversity of use cases, noted in particular through this research on dashboard design, data availability, and functionality for global health crises, I have written a series of "user stories" for each necessary element to be included by PaaS providers for future dashboard designs.

A user story is a concise, informal explanation of a software feature written from the perspective of the software's user (Rehkopf, "User stories with examples"). User stories are used throughout the software industry to help humanize software products and make the user the center of the development process (Rehkopf, "User stories with examples").). A user story should have a format which closely follows "As a [person], I need to [task that needs to be accomplished] so that [reason the task is important]." It should also provide a description of all the steps that are required to accomplish that task, and it should provide the developer with a clear sense of when the user story is "done" or when the feature has been fully developed.

I wrote the following user stories for each of the following functions: 1) data downloads, 2) language localization support, and 3) archiving methods. These user stories are designed to provide an actionable explanation of how PaaS providers could facilitate each of these capabilities to be more useful tools for potential future global health crises.

Data Download Options

Data download options help to preserve a record of data provenance for proper citation, give individuals new ways to explore and share information, and can preserve underlying data for posterity. The following user stories capture two perspectives on the features a PaaS provider would need to develop to provide data download functionality while maintaining data privacy.

> **User Story 1**: Journalism student wants to download accessible data format
>
> I am a journalism student who wants to do some research about how COVID-19 spread across my university. My university offers a dashboard which lets me query and zoom in on certain data in my county, but I do not have the technical expertise to query the API that they direct me to. I want to be able to download a spreadsheet of the data from the dashboard so that I can cite the data I am observing and tell my classmates about COVID-19 spread.

User story 2: Public health analyst wants to maintain data privacy

I am a public health data analyst for the State of Wisconsin. I want to connect my dashboard to an already-established API, but I can only allow users to download certain anonymized data fields from my overall dataset. I want the PaaS provider I provide to give my user's the opportunity to download data from my public-facing dashboard without having access to my state's entire public health database.

User Story 1 highlights how having a simple "download" button can increase engagement and utility of a dashboard for non-technical experts. While many dashboards connected to external databases and APIs this limits the number of people who can retrieve and interpret the data to specialized practitioners with the technical skills to navigate intricate data management systems. User Story 2 focuses on a dashboard developer who wants to integrate data download options while maintaining data privacy. The provision of data download options can make dashboards more engaging and actionable and should be easy to integrate into dashboard designs.

Language Localization

Language localization, or multi-language support, is necessary for large-scale institutions to make their information accessible to many demographic groups within the public and to mitigate error in interpreting the meaning of data. I wrote the following user stories to capture the needed features of a language localization system for a global health emergency.

User Story 3: Public health data analyst wants to integrate language localization

I am a data analyst for the city of Philadelphia's Public Health Department, and I want to allow people across my linguistically diverse population to access the dashboard I am designing. Since people in my metro area speak a wide variety of languages, my PaaS needs to be able to support languages which read left-to-right as well as right-to-left, and it needs to support special characters that may not be common in English. Also, since I sometimes have to rapidly provide information in response to a rapidly developing disease outbreak, I need multiple levels of time investment to deploy a multi-lingual dashboard. Ideally, there would be multi-lingual dictionaries for commonly used words on buttons such as "scroll," "zoom," and "download" that would be automatically set when my user switches languages so I could quickly design and deploy my dashboard, as well as opportunities to build out a more extensive translated dashboard.

User Story 4: Concerned user wants to easily understand a dashboard built in their second language

I am a recent immigrant to Philadelphia from Egypt, who is nervous and trying to understand a recent pandemic outbreak. My English is okay, but given the stress of the situation, I would prefer to read the dashboard my local data analyst has made in my native Arabic. Additionally, I would prefer for the numbers, dates, and times to be written according to my cultural standards, because I do not want to spend extra time converting numbers in my head.

User Story 3 captures the language localization needs of a public employee who is building a public health dashboard. In the case of the COVID-19 pandemic, dashboards were developed iteratively over two time scales—a short time scale to quickly distill information to citizens and a longer time scale to provide regular updates on the status of the pandemic. Ideally, a PaaS localization engine would have options for fast development and deployment of localized dashboards where the user interface (UI) could be easily translated into another language and a more in-depth way to add in translated data tables and descriptions. User Story 4 focuses on why language localization is important to the dashboard's end user, especially when a dashboard is a part of an emergency-response communication strategy. Although some individuals may be able to speak the language that the dashboard was developed in, it may provide additional translation and communication barriers during stressful times of crisis.

Archivability

Archival methods are important for researchers in the present and future to be able to access important ephemeral information and to reflect on ways to improve communications strategies. Archivability specifically refers to the ability to preserve a webpage to be able to access it for future reference and research. The following user stories represent two researchers from different fields who want to use web archiving for different research questions relating to COVID-19.

> **User Story 5**: Researcher wants to preserve computer interaction elements
>
> I am a computer interaction researcher from the University of Oregon, and I want to look back on the COVID-19 pandemic to understand accessibility in dashboard design. Since screenshots of dashboards divorce the dashboard from the interactivity, I need a way to access old or discontinued dashboards to study their features. I would be happy if each PaaS platform had an internal way to archive and retrieve public-utility dashboards, or if my dashboards of interest were compatible with the WayBack Machine.

> **User Story 6**: Public health expert wants a record of data provenance
>
> I am a public health policy expert from Austin, Texas. I am compiling a report on COVID-19 cases for a local think tank, but the dashboard I was using for my data was taken offline. Since I need to follow strict guidelines for citing my sources, I need a way to access old dashboards' data so I can cite them and record my data's provenance.

User Story 3 highlights the importance of figuring out ways to preserve all elements of a dashboard. Recently, online dashboards have been made more versatile by allowing the user to interact with and manipulate the displayed data. This user story highlights the importance of capturing a dashboard without divorcing it from its interactivity, like a screenshot would. User story 4 expands on that functionality for researchers who are looking to cite dashboards or official public health services. The inability to archive dashboards can be a significant hindrance to tracking data provenance, and identifying ways to build for archivability is important for maintaining research integrity.

A well-designed dashboard has the potential to rapidly distill high-quality information to a broad audience in global health disasters and other long-term, rapidly changing, high consequence events. However, across the dashboards I analyzed, there was significant variation in how dashboards displayed data and what functions were available to users. Interpreting this variation can help to give insights into the processes and pain points that dashboard designers encountered during the design process. The user stories provided in this chapter provide actionable synapses of a few workflows currently incompletely supported by major PaaS providers, but should also function as a jumping-off point to reframe how PaaS have become an integral part of global emergency response and communication.

Chapter 6: Conclusion

The goal of this thesis was to analyze variations in COVID-19 dashboard design and functionality to identify the key features that dashboard platforms must provide in times of global crisis. I used a content analysis, as described by Rose (2016), to systematically categorize the contents of each dashboard. My coding questions were derived from Bach *et al.'s* (2022) taxonomy of dashboard design patterns; observations I made across the 24 dashboards I analyzed, such as the inclusion of maps and the archivability of the dashboards; and other literature, including the provision of modeling future forecast data (e.g., Au *et al.* 2021), data download options (Praharaj *et al.* 2022), and language localization (Momenipour *et al.* 2021). By categorizing each dashboard, I was able to collect data on the design and functionality of each individual dashboard. In this thesis I aimed to answer three research questions about how COVID-19 dashboards differed in their design across national governments, how differences in dashboard functionality could be related to the platform as a service (PaaS) that a dashboard used, and what features could address pain points and limitations in dashboard building platforms. In this chapter, I summarize the findings and conclusions from each research question and address the challenges and limitations of this study.

Research Question 1

> RQ1: How did COVID-19 dashboards created by national government organizations differ in their design?

My analysis showed dramatic variation in the types and styles of layouts and designs that national governments used in their dashboards. The codes that addressed this research question were largely derived from Bach *et al.* and allowed for me to code for 1) Structure, 2) Visual

Representation, 3) Page Layout, 4) Screenspace, 5) Interaction, 6) Meta Data, and 7) Color. Among those categories, one notable result from my analysis regarded the interactivity of each dashboard, which indicated that 80% of dashboards (n = 20) favored limited interaction in what Sarikaya *et al.* (2019) describe as visual dashboards, not functional dashboards. This means that, on a global scale, COVID dashboard designers preferred designs that moderated the data presented to the user over more exploratory layouts, which past literature has found to lead to more direct and actionable dashboard design (Ivankovik *et al.* 2021) Future researchers can use these data to look more deeply at broader patterns in layout styles using a methodology such as a principal component analysis to identify any correlation between national design decisions and national COVID-19 containment strategies.

One other significant result from my content analysis was support for Au *et al.*'s (2022) characterization of the United States' COVID communication strategy focused on modeling future spread of COVID-19. Additionally, I would add to Au *et al.'s* (2022) analysis that this focus on data forecasting was unique to the United States, as no other country's dashboard that I analyzed included forecasted or modeled data. This finding leaves open the opportunity for future communications researchers to examine if and why this would be unique to the United States.

Research Question 2

> RQ2: How did national COVID-19 dashboards differ in the functionality of their dashboards for 1) data download options, 2) language localization, and 3) archivability? What impact did Platform as a Service (PaaS) providers have on the differences in functions between different countries' COVID-19 dashboards?

Like the variation in design choices between international dashboards, the functionality of COVID-19 dashboards varied dramatically. Specifically, I analyzed data download options, language localization, and archivability. First, among the 24 international dashboards I analyzed, only one third had options to download the displayed data, which follows similar results from Praharaj *et al.'s* study which was focused on the differences between US states' COVID-19 dashboards. Their research found that only half of US state's dashboards included options to download any underlying data. Even though all 4 most common PaaS providers in COVID-19 dashboard design allowed data download integrations in a dashboard, only one dashboard designed in a PaaS included options to download the underlying data. This could indicate that the challenge of integrating data download options is prohibitively challenging, or it could indicate that dashboard developers themselves need to collectively adhere to stronger data transparency standards. Next, one third of the dashboards I analyzed had options for toggling between multiple languages, known as *language localization*. Among the four most commonly used PaaS providers in COVID-19 dashboard design — Microsoft PowerBI, Tableau, Esri's Dashboard Builder, and Google's Looker studio — only Microsoft PowerBI and Tableau had options for language localization, meaning Esri and Google Looker Studio did not allow dashboard developers to include language localization features. Finally, only 63% of dashboards I analyzed (n = 15) were found to have some degree of archivability on the WayBack Machine. Microsoft Power BI's and Tableau's platforms were found to produce archivable pages (even if not all widgets were preserved), but Esri's Dashboard Builder and Google's Looker Studio were found not to be archivable. Through analyzing the functionality of international COVID-19 dashboards, I was able to identify gaps in PaaS functionality and pain points in the user experience that can help to inform future workflows for dashboard and software developers.

Research Question 3

> RQ3: What are common workflows PaaS providers should consider supporting for health disaster response dashboards?

Based on my findings, I created a list of features, in "Chapter 5: Discussion," that PaaS providers need to develop to respond to future public health emergencies more comprehensively. User stories are concise descriptions of workflows that are used throughout the software industry to help humanize software products and make the user the center of the development process (Rehkopf, "User Stories"). In creating user stories, I capture the findings from this work in an actionable format that can easily be adapted into PaaS software development workflows.

Challenges and Limitations

One of the most significant challenges as a researcher was trying to analyze COVID-19 dashboards in early 2023, as the global political body has largely moved to a "post-COVID" narrative. Amidst my attempts to study the global body of COVID-19 dashboards, the team behind the Johns Hopkins COVID-19 resource center announced that their dashboard would stop receiving any updates, citing a massive decrease in the number of countries actively reporting COVID-19 cases and diminishing funding for resources on that scale. Following their announcement, several countries likewise discontinued their dashboards, and 4 of the 28 dashboards I originally identified were removed from the Internet with no way for me to retrieve or access their information. The discrepancies in dashboard preservation and my personal challenge in trying to save dashboards for future researchers led me to start looking into how the dashboards I was researching were influenced by the platforms they were designed on, and significantly informed the conclusions of this thesis. However, these challenges are as formidable as they are informative and limited my ability to identify or analyze many dashboards that were developed following the initial outbreak of COVID-19.

In addition to the infrastructural challenges of dashboard longevity, one limitation to my study was that I was the only individual coding the dashboards, so there was no other researcher to double check my coding decisions. In future iterations of this research, and with more substantial funding, I hope to use an iterative coding process with another researcher to standardize our coding schemes and discuss any discrepancies in our results.

The goal of this thesis was to analyze variations in COVID-19 dashboard design and functionality to identify the key features that dashboard platforms must provide in times of global crisis. I hope that in providing these analyses they help to frame a larger conversation about how software companies and the platforms they provide have become an infrastructural cornerstone in our response to disasters on a local, national, and international scale. Through providing a thorough content analysis and an online, public archive of COVID-19 dashboard recordings, I hope to provide the data for future researchers to look into the role that these webpages played in communicating the developments in and the impacts of the COVID-19 pandemic. Finally, in drafting user stories for software companies, I hope that the insights from this analysis will be easily captured and implemented for future responders.

Bibliography

Atalay, Hatice, and N. Necla Uluğtekin. "The Importance of Cartography in Covid-19 Pandemic Mapping." Abstracts of the ICA 3 (December 13, 2021): 1–3. https://doi.org/10.5194/ica-abs-3-14-2021.

Au, Larry, Zheng Fu, and Chuncheng Liu. "'It's (Not) Like the Flu': Expert Narratives and the COVID -19 Pandemic in Mainland China, Hong Kong, and the United States." Sociological Forum 37, no. 3 (September 2022): 722–43. https://doi.org/10.1111/socf.12819.

Bondarenko, Andrii. n.d. "How to Write a Good User Story: With Examples & Templates." Accessed April 24, 2023. https://stormotion.io/blog/how-to-write-a-good-user-story-with-examples-templates/.

Brewer, Cynthia A. Designing Better Maps: A guide for GIS Users, second edition. Esri Press. Redlands: Esri, 2016. ISBN 978-1-58948-440-5 (paperback).

Chang, Chingching. "Cross-Country Comparison of Effects of Early Government Communication on Personal Empowerment during the COVID-19 Pandemic in Taiwan and the United States." Health Communication 37, no. 4 (March 21, 2022): 476–89. https://doi.org/10.1080/10410236.2020.1852698.

"COVID Data Tracker." US Center for Disease Control and Prevention. Johns Hopkins Health and Medicine, 2022. Accessed Dec 4, 2022. https://coronavirus.jhu.edu/map.html .

"COVID-19 Dashboard." Johns Hopkins Center for Systems Science and Engineering. US Department of Health and Human Services, Dec 2022. Accessed Dec 4, 2022. https://covid.cdc.gov/covid-data-tracker/#cases-deaths-testing-trends .

Cromley, Ellen, and Sara L. McLafferty. GIS and Public Health. The Guilford Press. New York: Guilford Publications, 2012. ISBN 978-1-60918-750-7 (Hardback).

Dangermond, Jack, Corrado De Vito, and Christiano Pesaresi. 2020. "Using GIS in the Time of the COVID-19 Crisis, Casting a Glance at the Future. A Joint Discussion." *Journal of Research and Didactics in Geography* Vol. 1, Year 9 (June).

"How to Localize Content in Tableau." n.d. Tableau. Accessed May 8, 2023. https://www.tableau.com/learn/whitepapers/how-localize-content-tableau.

Fish, Carolyn. 2020. "Climate Change Maps in the US Media 2012-2017 and Content Analysis," January. https://doi.org/10.7264/58x2-g466.

Fish, Carolyn and Katie Quines Kreitzberg. "Mapping in an Echo Chamber: How Cartographic Silence Frames Conservative Media's Climate Change Denial." Unpublished manuscript, 2022. typescript.

Griffin, Amy L. "Trustworthy Maps." Journal of Spatial Information Science, no. 20 (June 25, 2020): 5–19. https://doi.org/10.5311/JOSIS.2020.20.654.

Ivanković, Damir, Erica Barbazza, Véronique Bos, Óscar Brito Fernandes, Kendall Jamieson Gilmore, Tessa Jansen, Pinar Kara, et al. 2021. "Features Constituting Actionable COVID-19 Dashboards: Descriptive Assessment and Expert Appraisal of 158 Public Web-Based COVID-19 Dashboards." *Journal of Medical Internet Research* 23 (2): e25682. https://doi.org/10.2196/25682.

Jiang, Julie, Emily Chen, Shen Yan, Kristina Lerman, and Emilio Ferrara. "Political Polarization Drives Online Conversations about COVID -19 in the United States." Human Behavior and Emerging Technologies 2, no. 3 (July 2020): 200–211. https://doi.org/10.1002/hbe2.202.

Kim, Do Kyun David, and Gary L. Kreps. "An Analysis of Government Communication in the United States During the COVID-19 Pandemic: Recommendations for Effective Government Health Risk Communication." World Medical & Health Policy 12, no. 4 (December 2020): 398–412. https://doi.org/10.1002/wmh3.363.

Kinkeldey, Christoph, Alan M. MacEachren, and Jochen Schiewe. "How to Assess Visual Communication of Uncertainty? A Systematic Review of Geospatial Uncertainty Visualisation User Studies." The Cartographic Journal 51, no. 4 (November 2014): 372–86. https://doi.org/10.1179/1743277414Y.0000000099.

Kyun, Do, Kim David, and Gary Kreps. n.d. "An Analysis of Government Communication in the United States During the COVID-19 Pandemic: Recommendations for Effective Government Health Risk Communication." *World Medical and Health Policy Journal* 12 (4). https://doi.org/doi: 10.1002/wmh3.363.

Lecher, Betina, and Ann Fruhling. 2014. "Towards Public Health Dashboard Design Guidelines." In *HCI in Business: First International Conference, HCIB 2014, Held as Part of HCI International 2014, Heraklion, Crete, Greece, June 22-27, 2014. Proceedings*, edited by Fiona Fui-Hoon Nah, 8527:49–59. Lecture Notes in Computer Science. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-07293-7.

"Localization Introduction - Globalization." 2022. January 31, 2022. https://learn.microsoft.com/en-us/globalization/localization/overview.

"Localizing Your LookML Model | Looker." n.d. Google Cloud. Accessed May 8, 2023. https://cloud.google.com/looker/docs/model-localization.

Lu, Jiahui. "Themes and Evolution of Misinformation During the Early Phases of the COVID-19 Outbreak in China—An Application of the Crisis and Emergency Risk Communication Model." Frontiers in Communication 5 (August 14, 2020): 57. https://doi.org/10.3389/fcomm.2020.00057.

Madill, Wendy. 2022. "What Is Localization?" March 7, 2022. https://localizejs.com/articles/what-is-localization/.

Milner, Greg. 2020. "Creating the Dashboard for the Pandemic." *Esri* (blog). August 26, 2020. https://www.esri.com/about/newsroom/arcuser/johns-hopkins-covid-19-dashboard/.

Momenipour, Amirmasoud, Salvador Rojas-Murillo, Brandon Murphy, Priyadarshini Pennathur, and Arunkumar Pennathur. 2021. "Usability of State Public Health Department Websites for Communication during a Pandemic: A Heuristic Evaluation." *International Journal of Industrial Ergonomics* 86 (November): 103216. https://doi.org/10.1016/j.ergon.2021.103216.

Muelenhaus, Ian. Web Cartography: Map Design for Interactive and Mobile Devices. CRC Press Boca Raton: Taylor & Francis Group, 2014. ISBM 978-1-4398-7622-0 (Hardback).

Patino, Marie. 2021. "The Rise of the Pandemic Dashboard." *Bloomberg.Com*, September 25, 2021. https://www.bloomberg.com/news/features/2021-09-25/why-every-government-needs-a-covid-dashboard.

Rajabiford, Abbas, Daniel Paez, and Greg Foliente. 2021. *COVID-19 Pandemic, Geospatial Information, and Community Resilience: Global Applications and Lessons*. 1st ed. Boca Raton: CRC Press. https://doi.org/10.1201/9781003181590.

Rose, Gillian. "Content Analysis." In Visual Methodologies: An introduction to research with visual materials, 4th ed., 85-105. SAGE, 2001. https://doi.org/10.1002/9780470669488.ch17.

Rose, Gillian. "Discourse Analysis." In Visual Methodologies: An introduction to research with visual materials, 4th ed., 186-219. SAGE, 2001. https://doi.org/10.1002/9780470669488.ch17.

Rehkope, Max. n.d. "User Stories | Examples and Template." Atlassian. Accessed April 24, 2023. https://www.atlassian.com/agile/project-management/user-stories.

Sarikaya, Alper, Michael Correll, Lyn Bartram, Melanie Tory, and Danyel Fisher. 2019. "What Do We Talk About When We Talk About Dashboards?" *IEEE Transactions on Visualization and Computer Graphics* 25 (1): 682–92. https://doi.org/10.1109/TVCG.2018.2864903.

Tagliacozzo, Serena, Frederike Albrecht, and N. Emel Ganapati. "International Perspectives on COVID-19 Communication Ecologies: Public Health Agencies' Online Communication in Italy, Sweden, and the United States." American Behavioral Scientist 65, no. 7 (June 2021): 934–55. https://doi.org/10.1177/0002764221992832.

Torkington, Simon. 2023. "Johns Hopkins to Close Pioneering COVID-19 Tracker." World Economic Forum. March 9, 2023. https://www.weforum.org/agenda/2023/03/covid-tracker-closing-down-johns-hopkins/.

"Using The Wayback Machine – Internet Archive Help Center." n.d. Accessed April 24, 2023. https://help.archive.org/help/using-the-wayback-machine/.

"WHO Coronavirus (COVID-19) Tracker." World Health Organization Emergency Disease Dashboard. World Health Organization, Dec 2022. Access date if no other date is available. https://covid19.who.int/ .

Xie, Ming, Steven Reader, and H. L. Vacher. Rethinking Map Literacy. SpringerBriefs in Geography. Cham, Switzerland: Springer International Publishing, 2021. https://doi.org/10.1007/978-3-030-68594-2.

Xie, Ming, University of South Florida, H.L. Vacher, University of South Florida, Steven Reader, University of South Florida, Elizabeth Walton, and University of South Florida. "Quantitative Map Literacy: A Cross between Map Literacy and Quantitative Literacy." Numeracy 11, no. 1 (January 2018). https://doi.org/10.5038/1936-4660.11.1.4.

Young, Gareth W., and Rob Kitchin. 2020. "Creating Design Guidelines for Building City Dashboards from a User's Perspectives." *International Journal of Human-Computer Studies* 140 (August): 102429. https://doi.org/10.1016/j.ijhcs.2020.102429.

Zhao, Bo, Mahyeon Kim, and Eun Woo Nam. "Information Disclosure Contents of the COVID-19 Data Dashboard Websites for South Korea, China, and Japan: A Comparative Study." Healthcare 9, no. 11 (November 1, 2021): 1487. https://doi.org/10.3390/healthcare9111487.