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Project APRED: A web-based data analytics platform for supporting community disaster resilience

Ike Obi
Logan J. Paul, MS
William Liao, MS
Mariem Loukil, PhD Student
Soichi Hayashi, BS
Max Comer
Carol O. Rogers, MS
David J. Wild, PhD
Patrick C. Shih, PhD

ABSTRACT

In this paper, we introduce the Analysis Platform for Risk, Resilience, and Expenditure in Disasters (APRED)—a disaster-analytic platform developed for crisis practitioners and the economic developers across the United States. APRED provides practitioners with a centralized platform for exploring the disaster resilience and vulnerability profiles of all counties across the United States. The platform comprises five sections including: (1) Disaster Resilience Index, (2) Business Vulnerability Index, (3) Disaster Declaration History, (4) County Profile, and (5) Storm History sections. We further describe our end-to-end human-centered design and engineering process that involved contextual inquiry, community-based participatory design, and rapid prototyping with the support of US Economic Development Administration representatives and regional economic developers across the United States. Findings from our study revealed that distributed cognition, content heuristic, shareability, and human-centered systems are crucial considerations for developing data-intensive visualization platforms for resilience planning. We discuss the implications of these findings and inform future research on developing sociotechnical visualization platforms to support resilience planning.

Key words: computational science, data analytics, information visualization, human–computer interaction, disaster planning, disaster response, community resilience

INTRODUCTION

Disaster events are more destructive in communities with infrastructural, socioeconomic, and geological vulnerabilities.[1] Weather disaster events cost communities around the United States $1.75 trillion from 1980 to 2019[2] with 2017 being the most expensive at $306.2 billion, and an increasing number of billion-dollar disaster events occurring within each year.[3] We surmise that the cost of a disaster is a measure of the mismatch between risk and resilience—that is, if we had a perfectly tuned resilience for a particular disaster, the cost of the disaster would be greatly reduced. Indeed, it would not actually be a disaster—it would simply be an event. If this hypothesis is true, then we should be able to mitigate disaster cost by modulating resilience relative to risks.

We introduce *Analysis Platform for Risk, Resilience, and Expenditure in Disasters (APRED)*, a disaster-analytic platform designed to provide counties around the United States with insights that will empower them to foster community resilience

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as a means of reducing the cost of future disasters. The platform employs the Baseline Indicators for Communities[4] framework to compute and present information about the disaster resilience and vulnerability levels of all the counties across the United States. Specifically, *APRED* ingests data from StatsAmerica, US Economic Development Administration, Federal Emergency Management Agency (FEMA), and National Oceanic and Atmospheric Administration (NOAA) to provide insights on (1) business sectors within a county that might be more vulnerable to natural disasters; (2) socioeconomic sections of a county that might be more vulnerable to disaster events; (3) historical data of FEMA Disaster Declarations of all counties across the United States; (4) historical data of NOAA storm events that have taken place in all counties from the 1960s; (5) potential cost of disaster events; and (6) a summary of the economic and demographic profile of all counties across the United States. Taken together, the objective of the *APRED* platform is to present in-depth information on the disaster resilience and vulnerability levels of all counties across the United States.

In this paper, we describe the different sections of the APRED platform and share the knowledge gained from developing the platform with a human-centered design and engineering framework—using research through design as a lens.[5] We engaged 32 Economic Development Administration (EDA) and regional economic developers across three iterative development phases, including discovery research, community-based participatory design, and high-fidelity prototyping. The discovery research activities allowed us to engage the practitioners and stakeholders to better understand their information needs. The participatory design activities allowed us to engage practitioners and stakeholders in a design session to uncover their design and platform preferences. The high-fidelity prototyping and user acceptance testing activities allowed us to engage with the practitioners and stakeholders to seek their feedback on their beta version of the platform. Taken together, these activities allowed us to engage with the relevant stakeholders throughout the development process to ensure that the final version of the platform presents information in a way that empowers policymakers and practitioners to devise solutions that will improve the resilience levels of their communities. Our research questions were exploratory, and they include what are the usability outcomes of disaster analytic platforms developed with participatory design in conjunction with practitioners? And what are practitioner requirements for developing a disaster analytic platform?

Findings from our research showed that beyond uncovering insights from large datasets, the practitioners requested more context around each data point. For EDA representatives, they requested context on how the information from the platform will empower them to make informed decisions regarding its investments in various communities across the United States. And for the local economic developers they requested context around the data points to support them in making informed decisions on pathways to improving the resilience levels of their community. This finding shows that although information visualization platforms surface meaningful insights, stakeholders require contextual insights on how to act with the information. We also find that the practitioners were interested in ensuring that the information on the platform conforms to the regulatory requirements and interconnects with existing tools in their ecosystem. Practitioners also requested access to the raw visualization data to permit them to utilize the data in other ways than presented on the platform. The ability to download and share visualization artifacts was also common feedback.

In summary, our paper makes the following contributions:

(i). We present APRED, a disaster analytics platform developed to provide crisis practitioners with a centralized platform for exploring the disaster resilience and vulnerability profiles of all the counties across the United States.

(ii). We share insights gained from our human-centered design and engineering framework, which surfaced distributed cognition, content heuristic, shareability, and human-centered systems as important considerations for designing information visualization platforms for economic development and disaster response.

(iii). We share findings from the usability evaluation of the APRED platform and lessons learned from the development process of the platform.

In the next section, we draw on existing literature to discuss the importance of information visualization platforms to crisis response and how they serve as a sociotechnical infrastructure. We also highlight the importance of computational frameworks in the design of information visualization platforms for crisis response and economic recovery. We then provide an overview of the APRED platform followed by our technical architecture and data computation approach. We conclude with a discussion on lessons learned from the project and the design implications.

BACKGROUND

Information visualization platforms as socio-technical infrastructure

Information visualization platforms are knowledge infrastructures designed to inspire action.[6] Prior work by researchers have highlighted the importance of characterizing information visualization platforms as an infrastructure.[7-9] They surmise that equating the design of information visualization platforms as the construction of a physical infrastructure nudges software engineers and designers to move their focus from the "thing" being designed to the people to the "thing" is being designed for.[10] Their argument rests on two premises; first, that the people to be impacted by the outcome of a design artifact should have a say in the design of the said artifact to ensure that it does not impair their interest.[4] And second, beyond harm, it makes sense to include the eventual users of a product in the design process to learn from them about how the system can be designed to suit their processes and objectives.[4]

When further deconstructed from an epistemological lens, information visualization platforms are epistemic artifacts that contribute to the epistemological ecosystem of the relevant stakeholders. In this context, the owners of the epistemic ecosystem are the crisis responders, while the software engineers and designers are producers of artifacts that support the sensemaking process within the crisis response ecosystem. It, therefore, makes sense for software engineers to engage with the crisis practitioners during the development phase of the platform to ensure that the system is designed to suit their activities. Other researchers have also characterized information visualization platforms as socio-technical infrastructures.[11,12] And they argue that the affordances of information visualization platforms allow crisis practitioners to surface insights that empowers them to provide equitable socioeconomic services and distribution of resources to their communities.[11]

Information visualization for crisis practitioners and economic development

Crisis response practitioners have implemented information visualization platforms for numerous use cases, including response to earthquakes, hurricanes, flooding, and wildfires.[9,13,14] Other practitioners have also deployed information visualization platforms as a decision-support tool for combating extreme climatic conditions.[15] This increase in adoption rates within the disaster response community suggests that crisis practitioners and economic developers now perceive information visualization platforms as potent tools for disaster response and planning.[16,17]

Information visualization platforms help practitioners working on the same objective to establish a shared mental model.[18] This attribute is particularly crucial in the context of disaster response as it fosters better collaboration among different practitioners working together to resolve the impact of a disaster event. For example, information visualization platforms can facilitate better coordination and collaboration between economic development professionals and emergency managers working to resolve a disaster event. Information visualization platforms also allow practitioners to collaborate from disparate locations when responding to disaster events. In addition, its affordances allow practitioners to integrate data

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sources from different sections of their community, allowing them to gain better insight into the multifaceted impact of disaster events.[19]

Computational models for disaster planning

In comparison to manual methods, computational disaster planning systems significantly improve the ability of stakeholders to plan and recover from disaster events. These systems typically rely on high-performance computing systems and computational models to generate insight. One such computational model is the Baseline Resilience Indicators for Communities (BRICS) developed by Cutter et al.[4] to help researchers to compare and track the resilience indicators of communities in the United States over time. Cutter et al.'s[4] framework folds the resilient and vulnerable variables of a city into a unified set of indices—to produce aggregated information on the disaster resilience levels of all counties in the United States. The BRICS index comprises six categories for disaster resilience, including economic, social, environmental, institutional, infrastructural, and community capital categories. The APRED platform employed the Cutter et al.[4] BRICS to compute and present information on the disaster resilience levels of counties across the United States.

In the next section, we describe the different sections of the *APRED* platform.

THE ANALYSIS PLATFORM FOR RISK AND EXPENDITURE IN DISASTERS (APRED)

The APRED platform is hosted at *https://ctil.iu.edu/projects/apred-landing/*. The home page presents a brief introduction of the web application and provides users with the option of learning about the Use Cases and Frequently Asked Questions about the platform. The home page also introduces the top three features of the platform and allows users to click on the Open APRED button to gain access to the interactive map page (Figure 1).

Interactive map page

The interactive map page is displayed when you click on the Open APRED button on the home page of the platform. This page serves two main use cases; first, it allows the user to quickly view at the macro-level, the impact of various kinds of disaster across the United States. Users can also view disaster types and years for a more customized view of the macroimpact. Within this page, users can also use the drop-down button to view macro-information on the disaster resilience levels of all counties across the United States, across different years. Second, the interactive page also serves as a portal that permits users to navigate to a specific county of interest for a more in-depth information about the disaster resilience level of the given county. The next section describes the second use case in detail (Figure 2).

In-depth profile page

This section of the platform provides in depth information on the disaster resilience and vulnerability level of a given county. The information on this section is divided into five tabs (pages), including the County Profile, the FEMA Disaster Declaration History, Business Vulnerability Index, Disaster Resilience, and Storm History sections. We itemize these tabs and describe their features as follows (Figure 3).

County profile. The County Profile tab provides information on the demographic and economic attributes of a county. This information includes the age distribution, GDP, median household income, per capita income, population, and population density, for the selected county. Data on this section are derived from the Census Bureau, American Community Survey, and StatsAmerica. In deciding what information to present in this section, we engaged with the US Economic Development representatives and other local economic developers to uncover data points that will facilitate their day-to-day operations toward the goal of improving the resilience levels of communities across the United States. Hence, the information presented on this page allows practitioners to quickly gain insight into the demographic and economic status of a county. The section also provides affordances that allows practitioners to download, share, or print the information from the page (Figure 4).

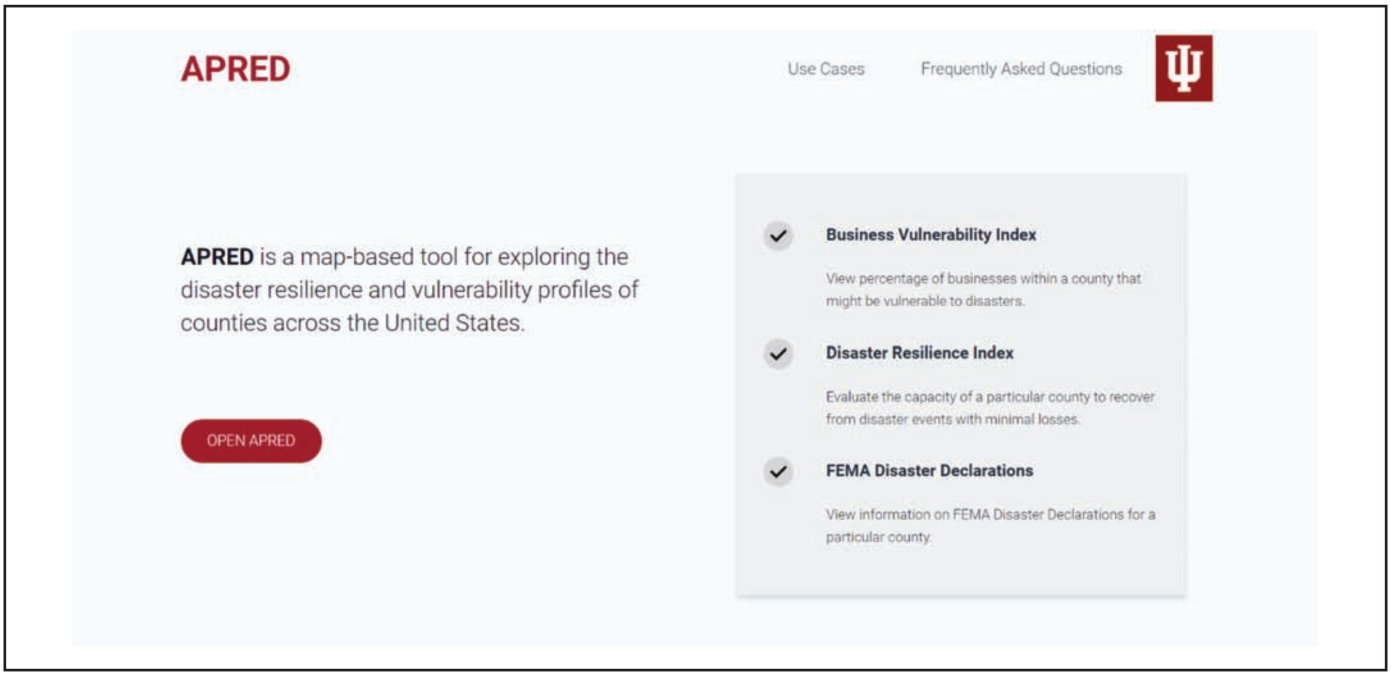

Figure 1. The home page of the APRED platform.

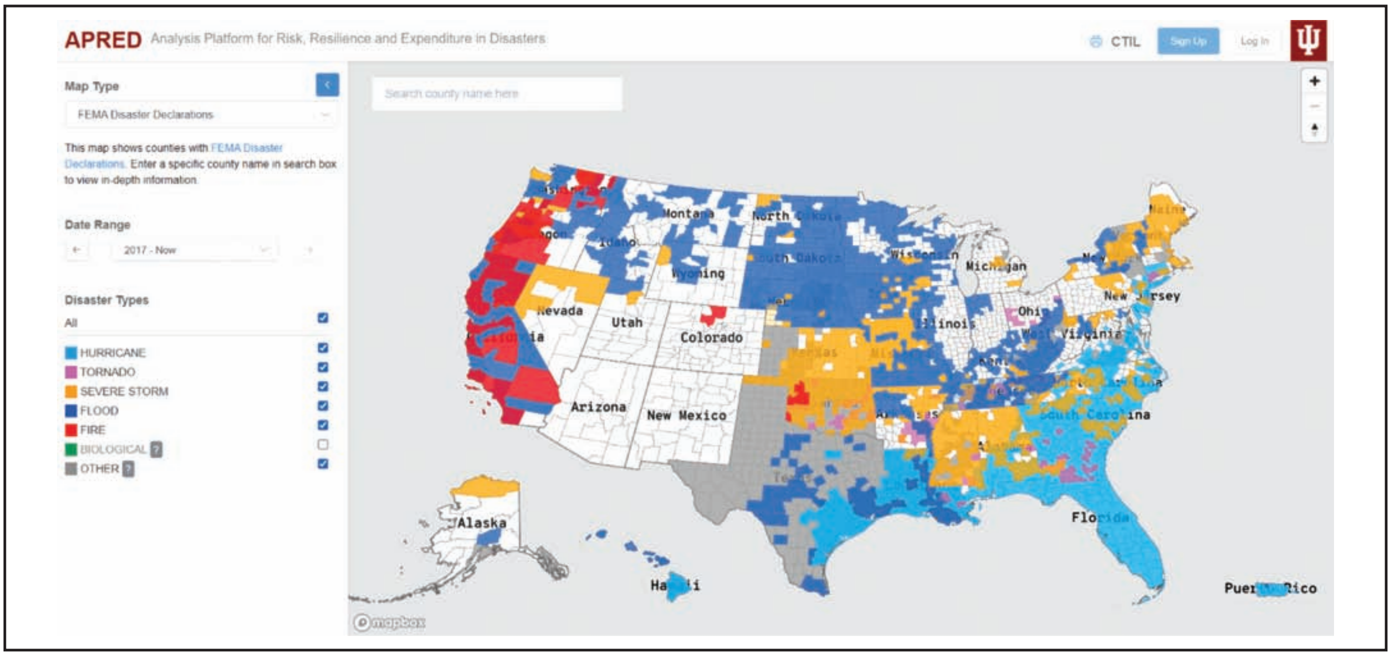

Figure 2. The interactive map page of the APRED platform.

FEMA disaster declaration. This tab provides historical information on all FEMA Disaster Declarations proclamations for a specific county from 1955 till date. Data on the tab are updated daily. The tab also links each disaster declaration to the FEMA website and maps the Public and Individual Assistance available for the disaster declaration number. Furthermore, the tab provides information about possible funding

Figure 3. The in-depth profile section of the APRED platform.

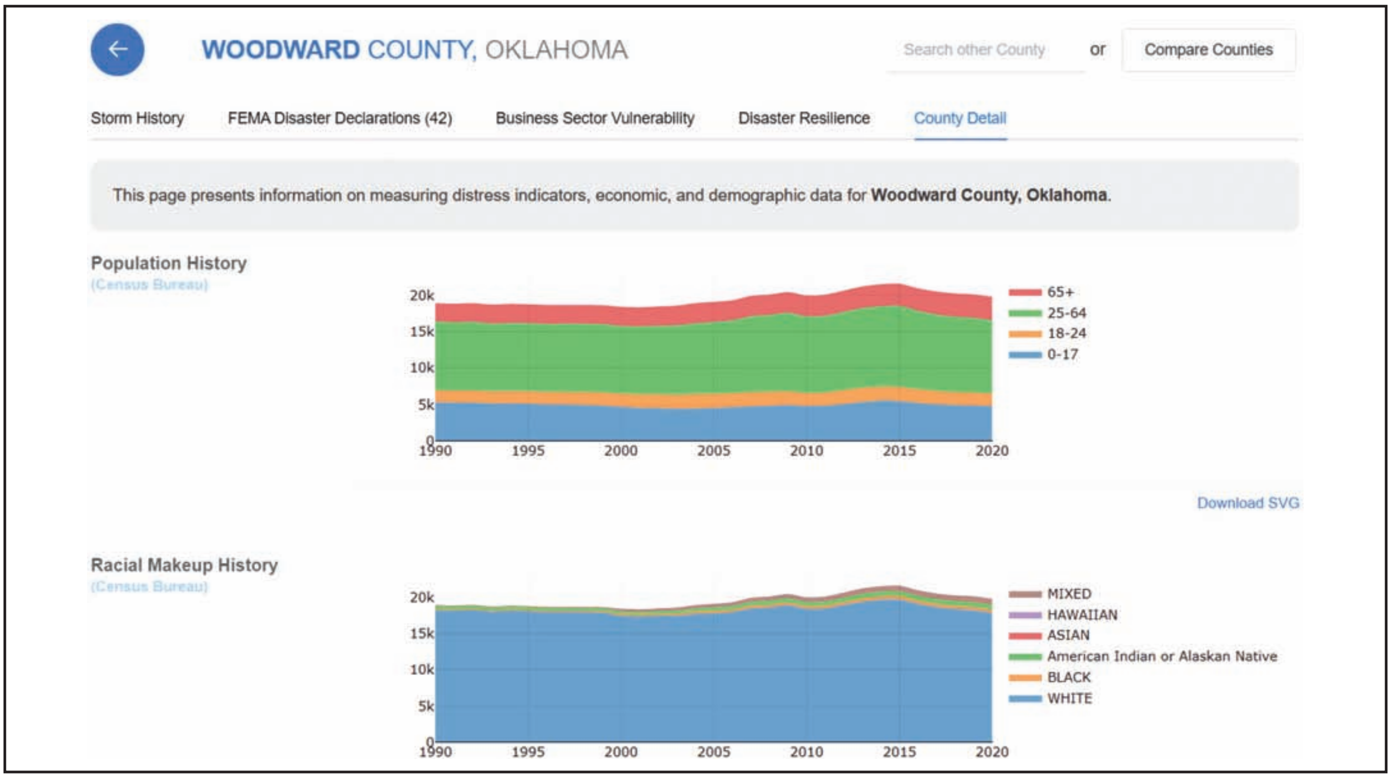

Figure 4. The county profile section of the APRED platform.

streams from the US EDA, and access to this information is limited to credentialed users who are knowledgeable about the requirements and nuances of the process (Figure 5).

Business Vulnerability Index. This tab provides information on the percentage of businesses within a county that is believed to be more vulnerable to natural disasters. Vulnerable businesses were identified to share the following characteristics: (1) dependence on supply chains, (2) high reliance on public utilities like water and electricity, and (3) large infrastructure footprint and low infrastructure mobility.[13] This tab breaks down the information into two categories showing the total number of businesses that are vulnerable and the total number of employees that could be affected if a disaster event were to impact the vulnerable business sectors under review. The information on this page is arranged according to business sectors (Figure 6).

Disaster Resilience. The Disaster Resilience Index measures the capacity of a community to recover from disaster events without losing their socioeconomic

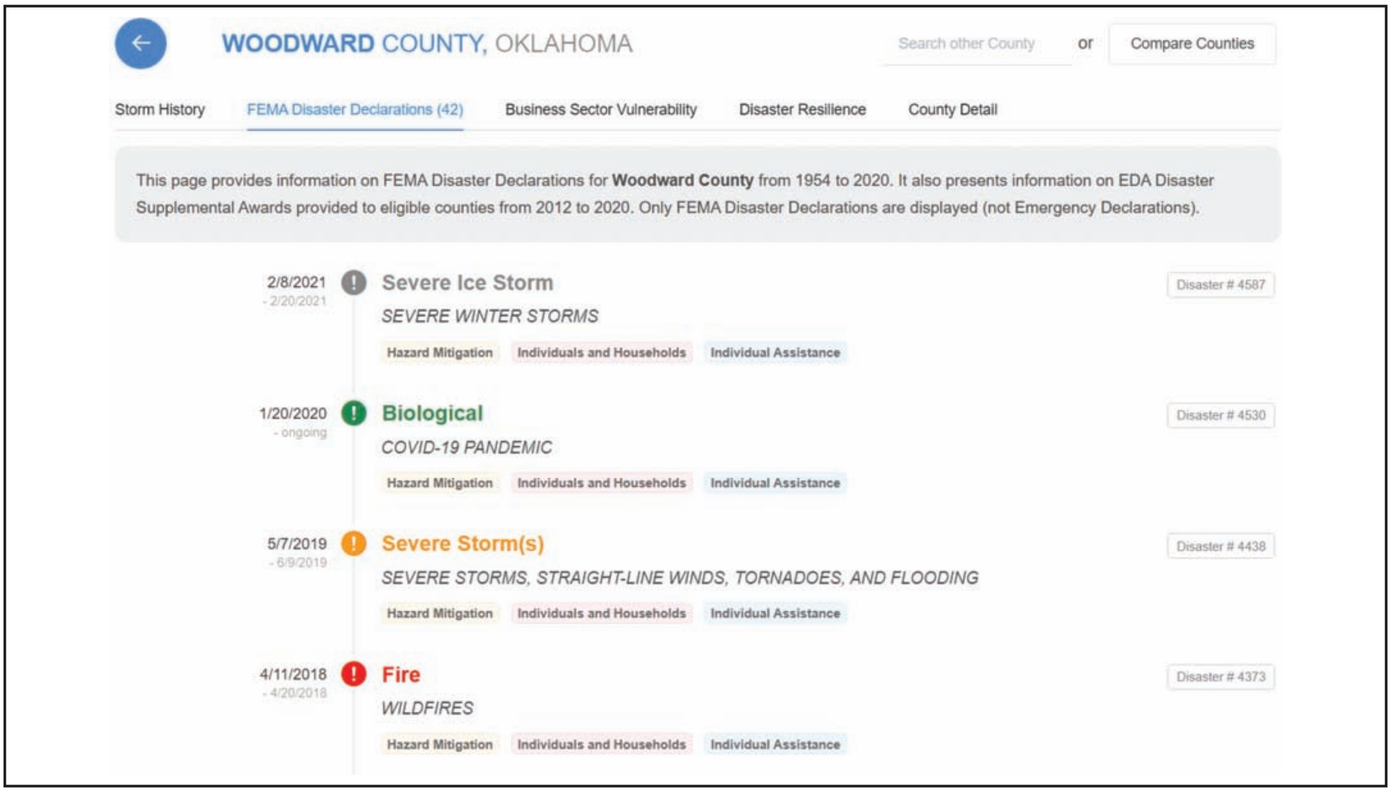

Figure 5. The FEMA Disaster Declaration section of the APRED platform.

and infrastructural viability.[15,17] Using the framework provided by Cutter et al.,[4] this index merges the resilient and vulnerable variables of a county into a unified set of indices—to produce aggregated information on their disaster resilience levels. The indices presented on the APRED platform comprises four categories, including social resilience, economic resilience, infrastructural resilience, and community capital. Within these major indices, other subindices are highlighted. The information on this section will allow the stakeholders to gain further insight on the socioeconomic profile of the selected county and how that might be impacted by a disaster event (Figure 7).

Storm History Section

The storm history tab provides information on the history of storm events for a specific county published by NOAA since the 1950s. This information provides insight into the frequency of storm events that are peculiar to the given county based on available records (Figure 8).

METHODOLOGY: (DESIGN PROCESS, TECHNICAL INFRASTRUCTURE, AND DATA COMPUTATION)

In this section, we describe our design process, technical infrastructure, and data computation approach for the implementation of the APRED platform.

Design process

We employed a human-centered design and engineering framework for the development of the platform. Our process consisted of three major phases including: (1) discovery research, (2) participatory design, and (3) high-fidelity prototyping (including user acceptance testing and usability evaluation). Within each phase, other user research activities were implemented (Figure 9). We designed this process with the mindset that design is not a ritual that has to be completed in a particular order. We, therefore, allowed ourselves the freedom to choose the order of the implementation of the project and what strategies to adopt for each phase based on how they

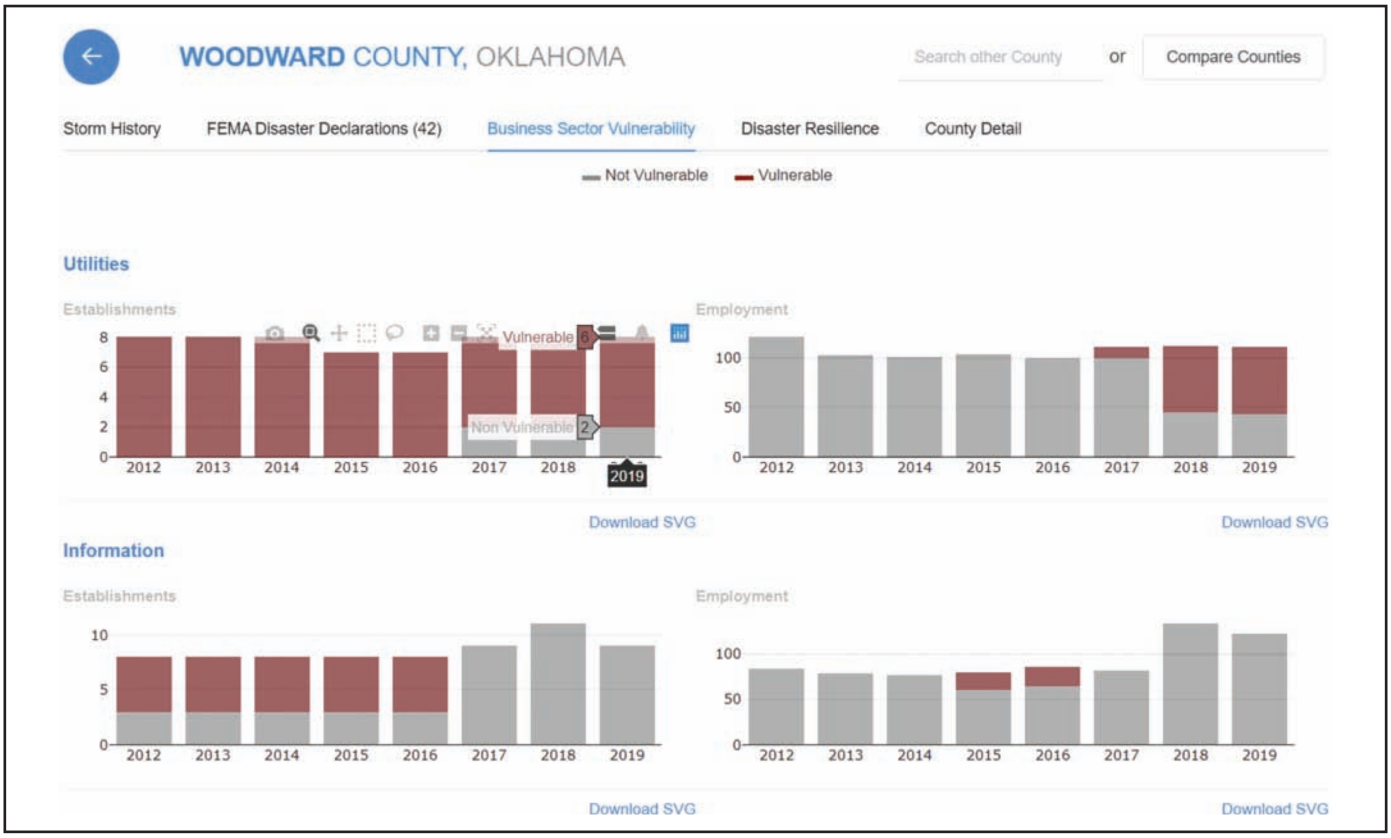

Figure 6. The Business Vulnerability Index section of the APRED platform.

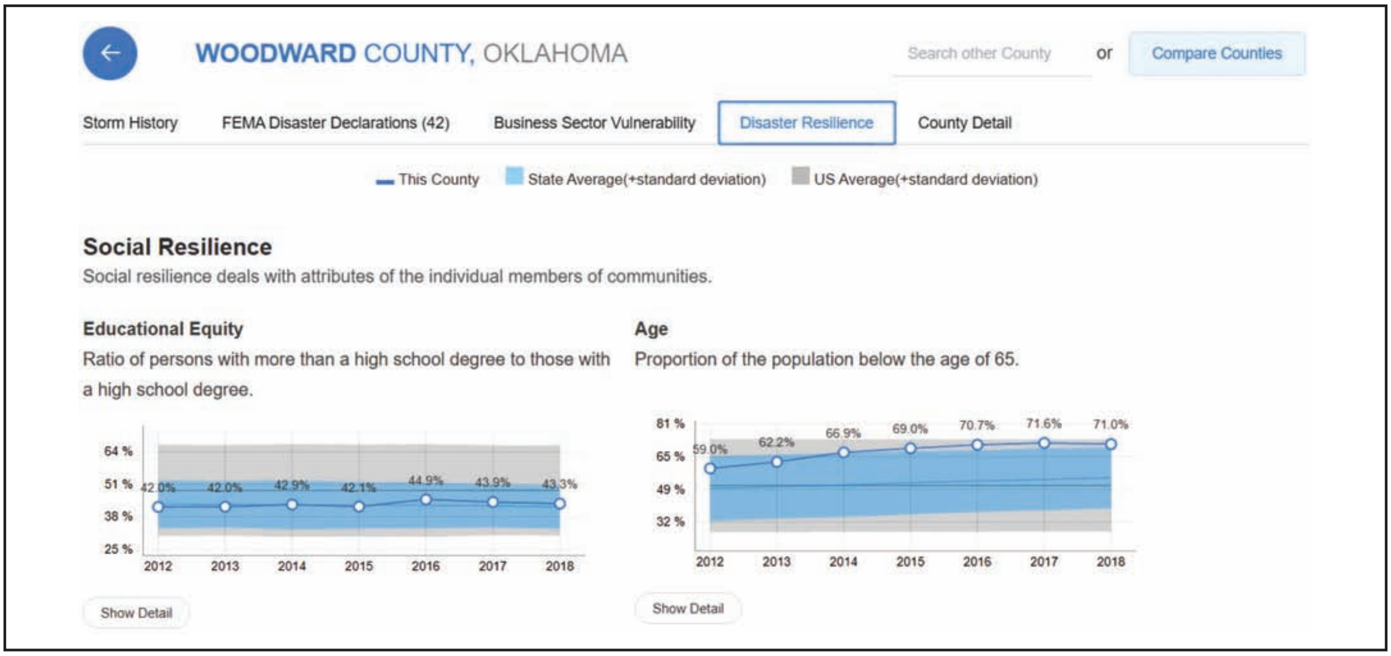

Figure 7. The Disaster Resilience section of the APRED platform.

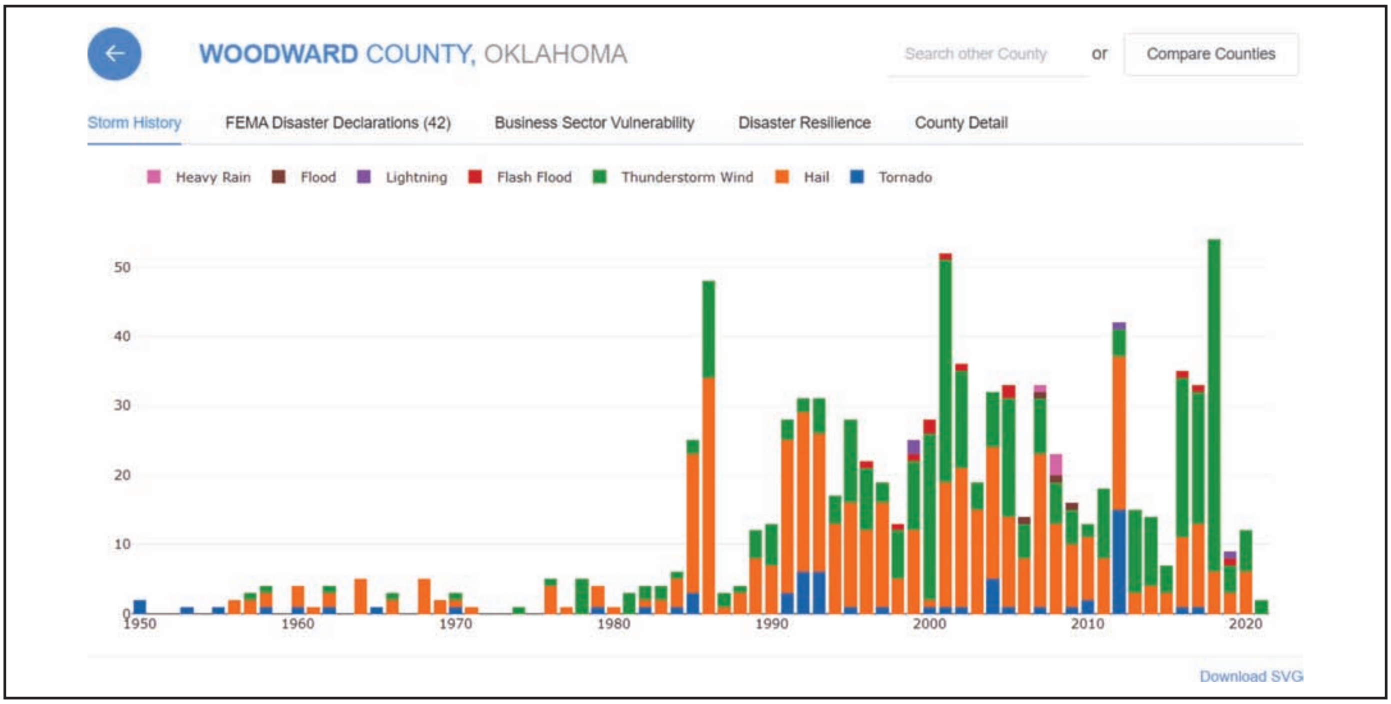

Figure 8. The storm history section of the APRED platform.

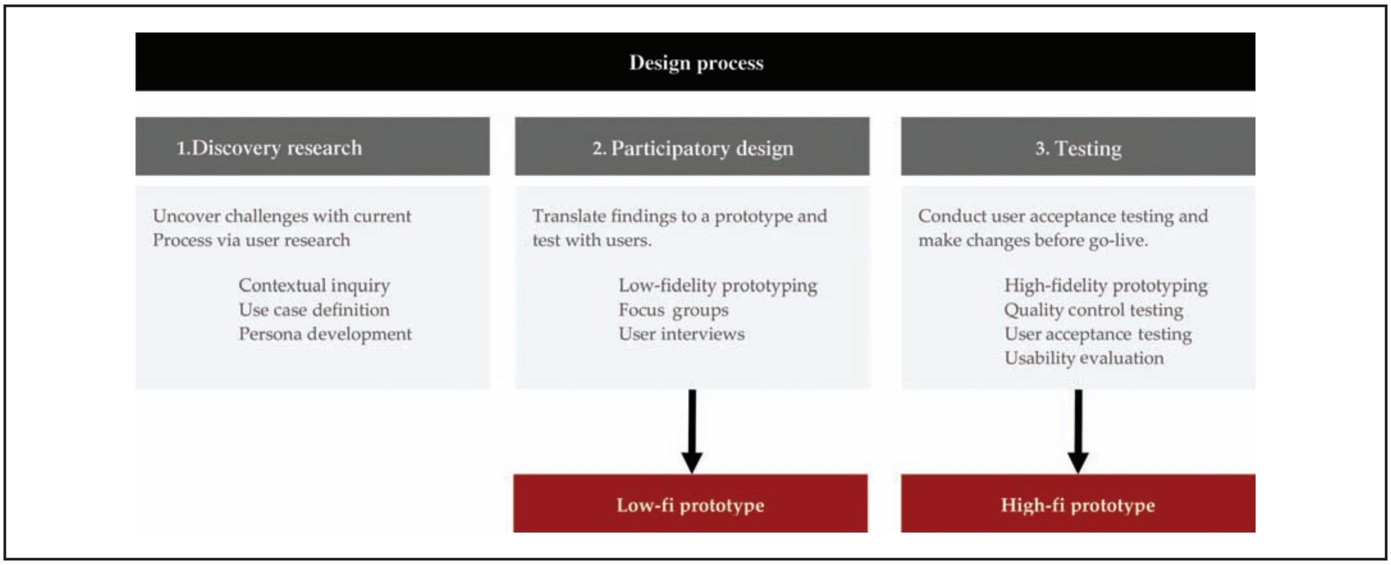

Figure 9. The development process.

complement our project objectives. During the sessions, we relied on observation, memo, and interview recording for data collection. We provide an overview of our process as follows.

Discovery research. We commenced the project by conducting discovery research to sensitize ourselves to the problem space. During this phase, we engaged four EDA Representatives and two local economic

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developers to learn about their information needs, current information-related challenges, and design requirements. We employed contextual inquiry approach for data collection. Contextual inquiry is a qualitative research methodology that allows for the observation of participants as they complete their daily work activities.[11] Contextual inquiry is particularly suited for this type of research as it allowed us to observe the workflow of the practitioners for signs of breakdown in interaction. During the session, the practitioners were encouraged to speak-out-loud to allow the researcher into their thought-process.[20] These observation sessions allowed us to view first-hand the difficulties practitioners face while attempting to obtain information to support the activities. We describe the contextual inquiry process below.

Contextual inquiry. We carried out a contextual inquiry study with four EDA representatives and two local economic developers to uncover the difficulties they face obtaining the information they need to support their activities. The inclusion criteria for participation in the session involved that participants should have experience applying for or reviewing EDA grant applications. We, therefore, excluded anyone who did not meet this criterion and who is not a member of the local economic development community. This requirement helped us recruit only those knowledgeable about the related crisis response ecosystem.

Before the contextual inquiry session, we developed a framework to guide our observation activities. This framework consisted of four categories that were designed to surface the core challenges the stakeholders were experiencing. It consisted of data meaning, data sources, use cases, and user sections. The data meaning section investigates the connotation attached to each data point, and how it influences decision-making process; the data source section reveals the platforms where practitioners currently obtain information for their decision-making process; the use case section describes how the processed information is used for decision-making purposes; the user section describes categories of users that are experiencing the challenges. Next, we employed the framework as a guide during the session to observe the practitioners in their work ecosystem and process.

Our session was organized into two phases: synchronous and asynchronous phases. The synchronous session was held once and lasted for about an hour. The session was conducted via an online video conferencing platform due to the distributed nature of the team. During the synchronous session, we observed the stakeholders as they completed their tasks in their digital work environment. This observation allowed us to uncover instances of breakdown in information interaction and how it impacted their workflow. Next, we followed up the synchronous session with an asynchronous discussion using Google docs as our collaboration environment. During this process, we provided participants with the records we took from the observation session and asked that they verify the accuracy of our characterization of their process and current challenges. Further discussions continued in the document until we reached saturation with the requests for clarification. The asynchronous session also allowed us to engage with the stakeholders to ask follow-up questions and to understand why they engaged in some of the actions during the synchronous sessions.

Altogether, conducting a contextual inquiry allowed us to observe firsthand the challenges the stakeholders face when navigating multiple websites to get the information they need to support their activities. It also exposed us to the intricacies of their work process and provided us with initial insights on how to design solutions to resolve identified issues. We analyzed the findings using thematic analysis,[21] and based on our findings, we uncovered that two user personas will benefit the most from the development of the platform and they include (1) EDA representatives—within this group, we have various subgroups including EDA regional reps, EDA headquarters reps, among others; (2) local economic developers—within this group, we also have the Economic Development Districts, county administrators, among others. Next, we mapped the use cases and user stories to personas that will benefit from the development of the platform to set a human-centered foundation for the implementation of the project. Findings from our analysis also revealed the need for a centralized platform to reduce the number of websites practitioners visit to obtain the required information. Furthermore, it also revealed that stakeholders were interested in gaining insight into the overall disaster profile of the counties under their management.

Participatory design. Based on these findings from the contextual inquiry activities, we developed a limited-functional prototype of the platform and conducted a participatory design session with the stakeholders to solicit their ideas on possible features to implement on the platform. We executed the session using the focus group technique and allowing the practitioners to critique the prototype and contribute their design ideas without restrictions. The session also allowed us to immerse ourselves in the environment of the practitioners to understand how they think about their process, the things they care about, and most importantly, how they want the platform to be designed. We held two one-hour sessions with each category of practitioners. For the EDA representatives, a one-hour session was held with six participants via video conferencing platform due to the distributed nature of the team. And for the local economic developers, a one-hour session was held with two participants in the conference room of the participants' office premises.

We developed the prototype using a visualization content management platform. The platform was connected to our database and allowed for the visualization of the modeled datasets. The prototype employed a one-page visualization format dividing the screen into four grids: (1) the visualization grid that contains the map; (2) the eligibility grid provides information about potential eligibility for disaster-supplemental declarations; (3) the year grid that provides information on the range of years for the disaster event; and (4) the state's grid that allows the user to select the state of their interest.

Before the sessions, we shared URLs to the web-hosted prototypes with the practitioners. They were also encouraged to attend the session with their personal computers. During the sessions, we employed a semistructured feedback form—that we prepared in advance—as a guide for facilitating the session. The prompts in the feedback form allowed us to probe the practitioners for feedback on ease of use, terminology, use cases, among other requirements. We also allowed ourselves the freedom to investigate any other issue not mentioned in our guide, which emerged during the sessions (Figure 10).

Next, we utilized the prototype to guide our participatory design sessions. After the sessions, we conducted a thematic analysis of participant feedback to explore the common themes that emerged from the response of the practitioners to the prototype. Findings from this analysis revealed that usability challenges, content heuristics, and data context were the common themes across all the sessions. These findings formed the basis for further development of the platform.

High-fidelity prototyping, user testing, and usability evaluation. Feedback from the discovery research and participatory design phases produced valuable insights that allowed us to develop a high-fidelity prototype of the APRED platform. This prototype represented the first-ready to be deployed version of the APRED platform. The prototype comprised five sections, including the (1) County Detail, (2) FEMA Disaster Declaration, (3) Business Vulnerability Index, (4) Disaster Resilience, and (5) Storm History sections.

Next, we conducted a user acceptance testing with 32 participants (five EDA head office representatives, five EDA Regional representatives, and 22 Local Economic Development District representatives) to investigate how the platform satisfies their design requirements and to probe their feedback on other features identified during the participatory design sessions. We utilized a video conferencing platform for the testing activities. The testing session with the EDA headquarters representatives and the local economic development delegates lasted 1 hour. And the session with EDA regional office representatives lasted for 30 minutes. We collected data from sessions employing two methods: (1) focus groups for the EDA head office and the local economic development representatives; (2) empathy interviews for the EDA Regional representatives. Following the user acceptance testing activities, we further conducted a usability evaluation of the platform. We describe the process of user acceptance testing and usability studies below.

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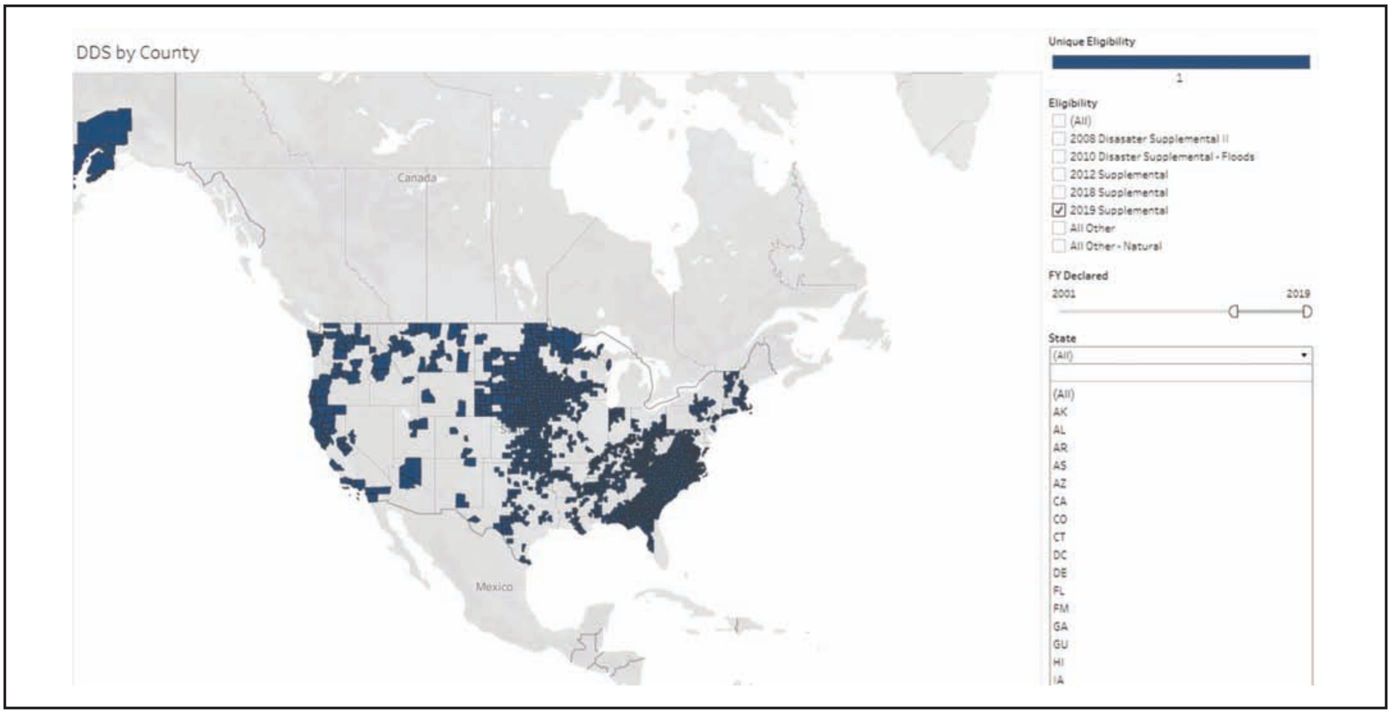

Figure 10. The low-fidelity prototype of the APRED platform.

User acceptance testing. Before the user acceptance testing activities, we conducted an internal quality control evaluation to review the beta version of the platform for (1) data accuracy, (2) completeness of information, (3) readability of content, (4) ease of navigation, (5) colors and shapes, (6) if any of the visualizations were overwhelming or confusing, (7) any other concerns that arose from our professional judgment. Conducting these internal checks allowed us to ascertain that the platform is functioning as intended in advance of the testing sessions. Following the internal system assessment, we transitioned to the user acceptance testing activities. The datasets we employed for the user acceptance testing sessions were real datasets that could be employed for real-life decisions. Furthermore, we also established the exit criteria that will determine the success or failure of the testing activities. And these criteria were based on the use cases we developed from the contextual inquiry studies.

Next, we conducted user acceptance testing activities with 32 participants (five EDA headquarter representatives, five EDA Regional representatives, and 22 Local Economic Development District representatives). During the testing session, we allowed the stakeholders to use the platform to complete a task like they would during their daily review or processing activities. This real-life testing of the platform allowed us to uncover requirements that require further adjustments to ensure that the platform functions at the optimal level when deployed for use in a live environment. We also tested the software documentation to ascertain that it presents applicable information to the practitioners.

Usability evaluation. Following the completion of the user acceptance testing activities, we also conducted a usability testing on the APRED platform before releasing it to the wider public. Six participants were recruited for the testing sessions. All the participants consented to participate in the study. Three of the participants (Participants 1, 2, and 5) were researchers at Indiana University in Bloomington, Indiana. The three other participants (Participants 3, 4, and 6) were economic developers, with two from the state of Indiana and one from the University of the Virgin Islands in the United States Virgin Islands. All six usability test sessions were conducted over a video conferencing platform. The participants were asked to perform tasks designed in advance of the study and then provide a

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rating for the Single Ease Question based on a five-point Likert scale. The time for completion of each task was recorded by viewing the recorded test sessions and observing the timestamp at which each task began and was completed. The time was not stopped once a task began; therefore, any questions or comments the participant may have had were included in the time to complete the task. Lostness values were also calculated for each task, using the following formula:

$$\sqrt{\left(\frac{N}{S}-1\right)^2 + \left(\frac{R}{N}-1\right)^2}$$

The tasks completed by the participants are as follows:

1. You are an economic developer who wants to know how you can use APRED to support your work. Find one of the use cases of the APRED platform that is applicable to your work.

- Endpoint: navigate to the use cases page
- *R*: 2
- Path: landing page → use cases page

2. You want to assess the economic background of Polk County, Florida. Obtain the unemployment rate for Polk County in January of 2021. Also, find the top five industries for the county.

- Endpoint: navigate to the County Detail page and scroll to the Unemployment Rate and Top Industries section of the platform
- *R*: 3
- Path: landing page → Disaster/Resiliency County Map → County Detail

3. You are now assessing Coffee County, Alabama, and want to know the previous FEMA Disaster Declarations that have taken place in Coffee County, Alabama. Determine what FEMA disasters were declared in Coffee, County, Alabama for 2020.

- Endpoint: navigate to the FEMA Disaster declaration data point for 2020
- *R*: 2
- Path: landing page → Disaster/Resiliency County Map
- Note: This task is counted as complete when finding information on the Disaster/Resiliency County Map or in the Disaster Declarations pages

4. You now want to know about which businesses would be most impacted by a natural disaster in Coffee County, Alabama. Determine the number of establishments in the accommodation and food service sector that would likely have been impacted by natural disasters in Coffee County, Alabama, for 2018. Then, download the chart.

- Endpoint: navigates to the Business Vulnerability section and then to the Accommodation and Food Services data point
- *R*: 4
- Path: landing page → Disaster/Resiliency County Map → County Detail → Business Vulnerability

5. Find the percentage of households in Coffee County, Alabama, that had access to a vehicle in 2018.

- Endpoint: navigate to the Disaster Resilience section and then to the Social Resilience section and Transportation Access chart

- *R*: 4
- Path: landing page → Disaster/Resiliency County Map → County Detail → Disaster Resilience

6. You want to compare information for Coffee County, Alabama, and Monroe County, Indiana. Find the total population for both counties.

- Endpoint: navigate to the comparison page and enter the list of the counties to be compared
- *R*: 4
- Path: landing page → Disaster/Resiliency County Map → County Detail → Compare Counties

Technical infrastructure

Our technical infrastructure mainly consists of (1) backend ETL scripts to load and transform data from StatsAmerica Database, (2) VueJS frontend codes which are used to show users the various data aggregated by the backend ETL scripts, and (3) an authentication service. The technical infrastructure of StatsAmerica played a significant role in how the infrastructure of APRED was designed since StatsAmerica provides data for the platform and will continue to update and manage the project after its completion. Figure 11 highlights our technical infrastructure.

Data source and computation

StatsAmerica provides the data platform for the entire APRED platform. All other data sources including from FEMA were curated and stored on the StatsAmerica database for sustainability of the project. The various data sources are updated frequently (ranging from daily to yearly depending on the data source) by StatsAmerica and used by the platform both in raw, eg, population, and calculated, eg, social resilience, ways to provide information to the user as seen on the platform.

Disaster resilience data are the most derived data presented in the platform. Each individual data point that is included in each of the resilience categories is calculated from other data sources including but not limited to the ACS and the Census Bureau data. These data are unique by individual measure, year, and county. These data are stored and used to calculate derivative measures, eg, overall resilience, Figure 12, and display temporal information, eg, social resilience over time, for each county. The data used for display on the platform are normalized within each year and individual measure on a 0 to 1 scale, following the method set out in Cutter et al.[4] Measure category values are calculated as the average of the individual measures within the category. The measure categories that we focused on during this study are social, economic, infrastructure, and community capital. Overall resilience is calculated as the sum of the available measure categories. The underlying database also contains data for each individual measure in a raw format that may be used for different purposes; these non-normalized data are especially useful for comparing counties and assessing the long-term impact of various stimulus without needing to account for changes in the minimum and maximum bounds that influence the normalization calculation.

Ongoing work is exploring utilizing the vast data infrastructure created by this project to assess the effectiveness of economic stimulus awarded to counties by means of project grants from the EDA. A major challenge of this undertaking is accounting for the latent effects of economic, social, and humane factors that add caveats to making a claim that any changes within a community are from the direct result of a given stimulus. Another major challenge is determining the temporal tail for the assessment of change; data underlying the resilience measures, eg, ACS, are slow-moving, and, thus, large changes from year-to-year are infrequent within our measures.

RESULTS

In this section, we describe findings from the different phases of the project and highlight how

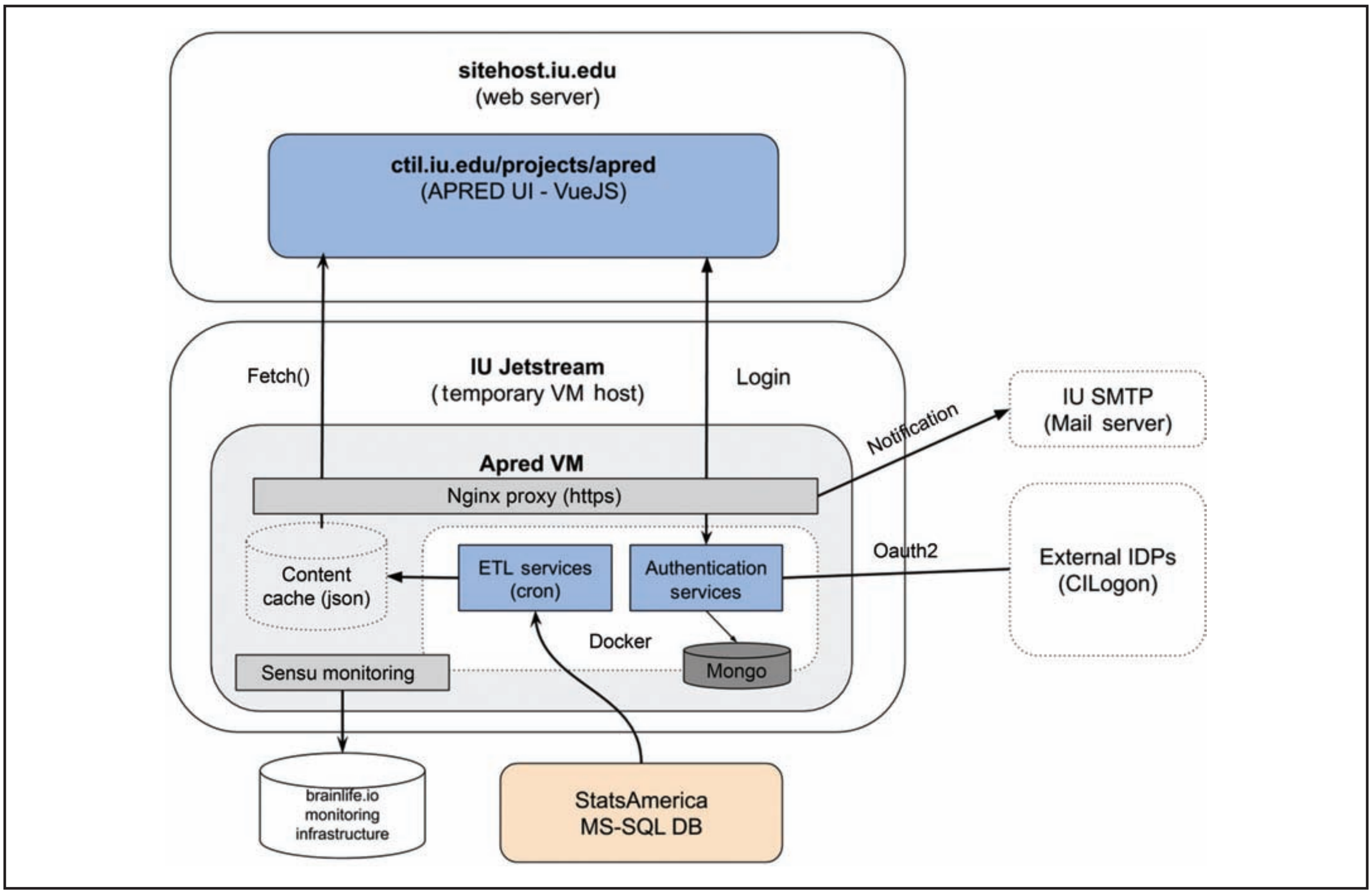

Figure 11. APRED technical infrastructure.

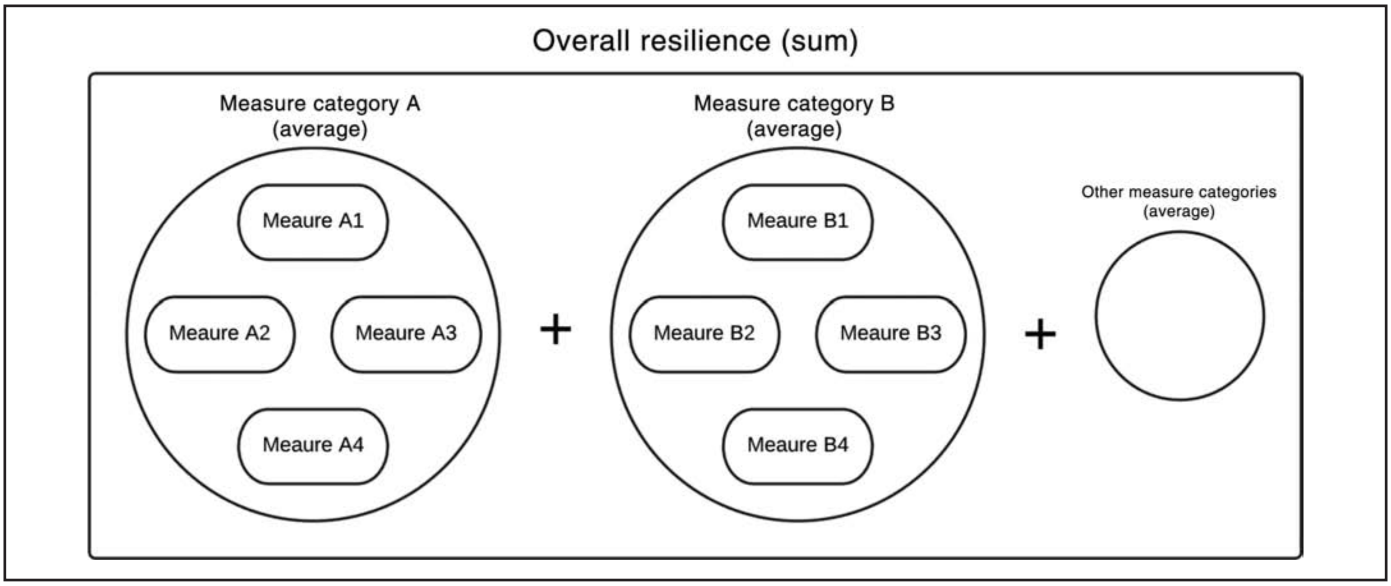

Figure 12. Disaster resilience calculation levels.

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the data generated from the user research activities influenced the development of the final product. We also share the lessons we learned from each phase of the project.

Phase 1: Findings from discovery research

Findings from the contextual inquiry studies revealed a breakdown in interaction flow as the practitioners visit multiple websites to obtain the information they need. It also indicated that practitioners are facing difficulties in gaining visibility into the disaster profile of counties across the United States—a necessary component to their sense-making process. Based on these findings, we identified critical design requirements for the development of the platform. We highlight these findings below and describe their contribution to the design process.

User-centered platform. Findings from the contextual inquiry studies revealed that the stakeholders consult multiple websites to obtain the information they need to support their activities. It also revealed that beyond visiting multiple websites, some practitioners employ search engines to investigate for additional data sources. For instance, P4 during the session mentioned that "I don't even know where to get the information I need, so I have to use Google to search anytime I need eligibility information." Based on these findings, we developed the initial use cases of the platform, which include that (1) the platform should provide all the relevant information in a centralized platform to empower the stakeholders to quickly get the information they need to support their activities. Specifically, the platform should mediate between all their data sources and resolve the fragmentation of their epistemic ecosystem concerning grant applications and review processes. (2) The platform should provide information on the disaster profile of all the counties in the United States. The goal is to present practitioners with insight on the disaster vulnerability levels of counties across the United States, including those within their control. Furthermore, based on the findings from the testing sessions, we identified that the user personas that would benefit from the platform included (a) EDA representatives—including the various subgroup—EDA regional reps, EDA headquarters reps, among others. (2) Local economic developers.

Distributed cognition. Findings from the contextual inquiry session also revealed that the stakeholders wanted the platform to serve as a common operating platform for coordinating with the various levels of crisis practitioners. During the session, P2 remarked that "The information we will get from this platform will help us to know what other resources we might need and who we might reach out to apply for grants. Obtaining this information is not the end of the process. It only makes the process more efficient." This comment by the participant alludes to the distributed nature of information within the ecosystem. Some of the required information are located within a different crisis response ecosystem. Based on these findings, we developed an additional use case for the platform, which includes that (1) the platform should provide artifacts and information in a way that is consistent with the representations and sense-making process within the crisis response ecosystem.

Phase 2: Findings from the participatory design session

The participatory design session allowed us to validate the use cases and the personas we developed to guide the implementation of the project. During this session, we presented the prototype to the practitioners for feedback. We utilized the feedback form to probe participants for insights on their design preferences and feature requests. We also learned about how the subpersonas within different persona groups differ in terms of their responsibilities and requirements. Following the sessions, we analyzed practitioner response and surfaced the following themes.

Usability issues. The most important finding from our participatory design session was that proprietary content-management data visualization platforms would not be suitable for our project due to usability challenges, limited customization options, and concerns about responsiveness. This finding was particularly crucial from an engineering perspective as it motivated our transition from a general-purpose visualization platform to a custom-built platform developed to accommodate the requirements of the project. From a usability perspective, the practitioners commented that using a pop-up to display additional information makes the map inoperable and less intuitive. In determining our architecture for a purpose-built visualization platform, we ensured that we employed fewer pop-ups as a way of displaying additional information on the platform and implemented other recommendations to improve usability. This finding marked an important transitional moment in the project life cycle.

Content heuristics. Another important finding from our research was that the practitioners wanted the descriptions of the data points to match the regulatory language where relevant. The results also revealed the importance of data accuracy and historical data to the workflow of stakeholders. This finding is crucial because the central objective of the platform is to present information in a way that empowers communities to prepare or recover from disaster events, hence, presenting inaccurate information can adversely impact the work of the practitioners. Taken together, the practitioners commented that the prototype allowed them to easily visualize counties that potentially qualify for disaster supplemental funding. Next, we relied on the findings from the participatory design session to develop a high-fidelity prototype of the platform. The following table presents a summary of findings from the participatory design sessions (Figure 13).

Findings from the high-fidelity prototyping and evaluations

Based on the findings from the contextual inquiry and participatory design sessions, we developed the beta version of the platform and conducted testing with practitioners to investigate how it fits into their information ecosystem. We conducted user acceptance testing and usability evaluation of the high-fidelity version of the platform.

Results from user acceptance testing sessions. Findings from the user acceptance testing sessions revealed that the platform fulfilled all the design requirements identified during the discovery research phase. For example, P18 mentioned that “I think this is very helpful. Before now, I used to go to the FEMA website, take pictures of the data on my phone and then visit the EDA website to verify the information… it is extremely helpful to have this information in one place and potentially saves me a lot of time” (P18). The findings also revealed that different user personas categories identified from the contextual inquiry study found the platform helpful. For example, P27 remarked that “this platform will provide me (EDA) and the local economic developers with the same information and this make it easy to collaborate” (P27) further confirming the distributed nature of the information in the ecosystem. In addition, we also received feedback from the stakeholders about incorporating even more links from other complementary data sources to reduce the time it takes to transition between websites to complete their duties. At the end of the user testing session, we conducted a usability testing session to ensure that the platform functions as intended when deployed in a live environment.

Results from usability evaluation sessions. Findings from the usability testing revealed that majority of all tasks were completed by the users without issues, indicating that the main functionalities of the platform were able to be used, and that the required information can be obtained by the practitioners from the platform without challenges. Figure 14 highlights this finding.

The mean lostness was also calculated for Participants 1, 2, 3, and 5. Recordings for Participants 4 and 6 were not captured due to human error. However, the chart indicates that the participants overall did not experience a high level of lostness. Task 3 shows a higher level of lostness than the other tasks, as none of the participants recognized that the FEMA Disaster Declarations could be located on the Disaster/Resilience Map and instead searched for a county and navigated to the “Disaster Declaration” section (Figure 15).

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Finding	Description	Design requirement
Usability challenges	The customized platform limited user control and freedom.	The new platform should allow the users the freedom to use the platform in ways that suit their work process and requirements.
	The pop-up in the customized platform makes it difficult for the users to select other options after using the map for the first time.	The new platform should enhance ease of use by eliminating options that induce error from the users.
	The customized platform takes time to load and does not work very well on slow networks.	The new platform should be light and should consider that some of the users work from resource constrained environments.
	The customized platform makes it difficult to add context around data points.	The new platform should add context around data points to make the information being presented on the platform easy to understand and use.
Content heuristic	The description of the data points does not match the regulatory requirements.	The customized platform should provide information according to the legal framework of the awards.
	Some of the information appears to be incomplete or inaccurate.	The final product should stress test the information sources to ensure that the information being presented on the platform is factual and complete.
	There is not enough historical data presented on the prototype.	The final product should include relevant historical information to allow the stakeholders to view changes in trends overtime.

Figure 13. Findings from the participatory design sessions.

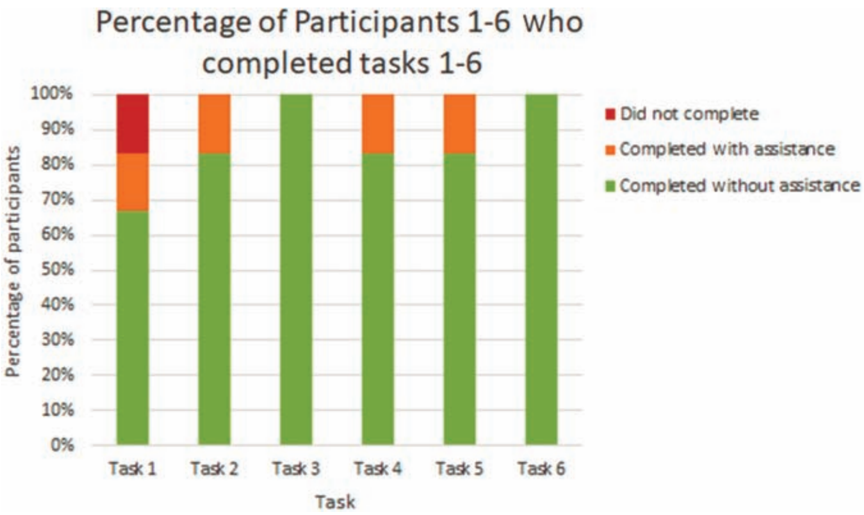

Figure 14. Task completion result of the APRED usability testing session.

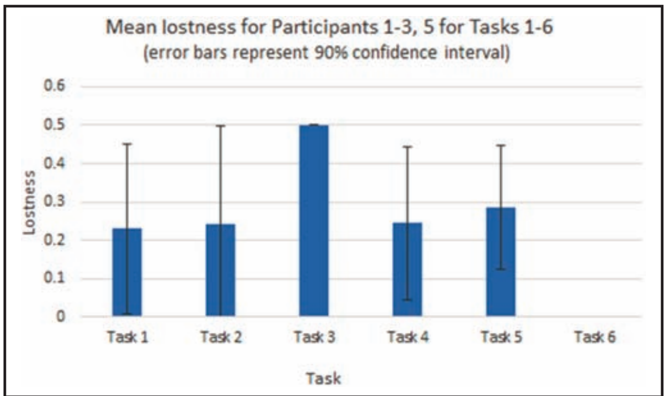

Figure 15. Mean lostness: APRED platform usability testing session.

DISCUSSIONS AND IMPLICATIONS

In this section, we discuss the lessons we learned developing the APRED platform. Our discussions provide valuable insights about developing information visualization platforms to support crisis response practitioners.

Information visualization platforms as an infrastructure

We often approach the design of information visualization platforms as a project that starts and ends when the development of the system is complete. This "projectization" approach to the design of information visualization platforms neglects the long-term interest of the community and the contribution of the tools to their sense-making process. For the implementation of the APRED platform, we equated the development of the system to the construction of a digital infrastructure where members of the economic development community will derive knowledge that will empower them to make informed decisions around resilience planning. This approach allowed us to focus on the practitioners who rely on the platform for their daily professional activities and information needs. If the system goes down, their work will be affected as they will be unable to complete their tasks. If the platform provides wrong information, people's lives will be adversely affected in some way. Hence, equating the development of the platform to the construction of infrastructure allowed us to approach the project with utmost care and to engage with the practitioners during the development of the platform. Just like you cannot build schools, hospitals, and bridges without conducting assessments of their potential impact on the community, you should not design information visualization platforms without considering the long-term interest of the community for which you are developing the platform. This approach was further validated by comments from the stakeholders. For example, P30 remarked, "when is the project ending, and how are you going to keep the data to date?" he went further "because we have had experiences when platforms just stop working and there is no one to contact after the project has ended" (P30).

Technology restrictions and burden of adopting new technologies

Due to the sensitive nature of the work of practitioners, they are restricted in the kinds of technology they can employ for their activities. Hence, it is important to empathize with them and ascertain early in the project about their technology requirements and then proceed based on those requirements. For example, we had participants using older versions of Internet Explorer and other browsers. We also had participants who were limited by the kinds of video conferencing platforms they could use. Therefore, we recommend conducting a systems requirement gathering study before the commencement of the project.

Beyond technological restrictions, some practitioners also expressed signs of fatigue from the adoption of new web platforms. Every new information visualization platform places an additional cognitive demand on practitioners, in addition to their already taxing work process. The cognitive demand arises because they need to learn how to use the platform, understand its value to their work process, among other onboarding requirements. In addition to the cognitive demands, every new platform leads to more fragmentation of information sources for the stakeholders. To resolve this fragmentation, we recommend that, where possible, a centralized platform should be created to bring together all the related information needs of the practitioners under one platform. This perspective is also supported by the feedback from the practitioners wanting more of the information they use for their activities to be added to the platform to reduce the number of websites they visit to complete a task.

Designing with the community

Participatory design is an implicit onboarding process that allows developers to continuously sell the value of their idea to the stakeholders throughout their collaboration in the project. This onboarding and trust-building mechanism enables engineers and practitioners to introduce themselves to each other's thought processes and value systems. The acclimation process is very vital for the implementation of a successful project as it allows both parties to appreciate the value the other brings to the project. Furthermore, soliciting feedback from the potential users of a platform ensures that information is being presented in a way that empowers them to achieve their goals. Based on these findings, we recommend the introduction of human-centered development methods into the data visualization process to ensure that the opinions of the practitioners and users are represented in the development of the information visualization platforms. The resultant process will to an eight-stage phase of implementing data visualization platforms, including discovery research, acquire, parse, filter, mine, represent, refine, interact, participatory design, and user testing phases. The combination of both methods will help to ensure that information visualization platforms are developed in ways that are easy for the users to engage and utilize for their activities.

CONCLUSIONS

In this paper, we introduced APRED, a disaster-analytic platform designed to provide counties around the United States with insights that will empower them to foster community resilience as a means of reducing the cost of future disasters. We shared our experience developing the platform for US EDA representatives and local economic developers through a human-centered design and engineering framework. Based on our findings, we surface that distributed cognition, content heuristic, shareability, and human-centered systems are crucial considerations for developing data-intensive visualization platforms for resilience planning. Furthermore, we discuss the importance of equating the design of information visualization platforms to the construction of socio-technical infrastructure, arguing that this perspective helps developers adopt a long-term view of how to support the system after the project has ended. We also examined the importance of providing context around visualization artifacts, in addition to resources that will help the stakeholders to actuate the information presented on the platform. Beyond requirements, we also explore the benefit of adopting a participatory

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design framework for the implementation of data visualization projects, arguing that it helps to foster trust and a sense of community between the developers of the platform and the community the platform is being designed to support.

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Ike Obi, Research Engineer, Luddy School of Informatics, Computing, and Engineering, Indiana University Bloomington, Bloomington, Indiana.

Logan J. Paul, MS, Senior Lecturer, Informatives Scheduler, School Curriculum Committee, Luddy School of Informatics, Computing, and Engineering, Indiana University Bloomington, Bloomington, Indiana.

William Liao, MS, Data Scientist, Postal, Bloomington, Indiana.

Mariem Loukil, PhD Student, Research Assistant, Crisis Technologies Innovation Lab, Luddy School of Informatics, Computing, and Engineering, Indiana University Bloomington, Bloomington, Indiana.

Soichi Hayashi, BS, Senior Software Engineer/Architect, Luddy School of Informatics, Computing, and Engineering, Indiana University Bloomington, Bloomington, Indiana.

Max Comer, Luddy School of Informatics, Computing, and Engineering, Indiana University Bloomington, Bloomington, Indiana.

Carol O. Rogers, MS, Director, Indiana Business Research Center, Kelley School of Business, Indiana University Bloomington, Bloomington, Indiana.

David J. Wild, PhD, Professor of Informatics and Computing, Crisis Informatics Track Director; Director, Crisis Technologies Innovation Lab (CTIL); Director, Integrative Data Science Lab, Luddy School of Informatics, Computing, and Engineering, Indiana University Bloomington, Bloomington, Indiana.

Patrick Shih, PhD, Assistant Professor, Department of Informatics, Indiana University Bloomington, Bloomington, Indiana.

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