iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 **Issue:** X **Month of publication:** October 2022

DOI: https://doi.org/10.22214/ijraset.2022.47179

www.ijraset.com

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue X Oct 2022- Available at www.ijraset.com

Data Visualization and Analysis of COVID-19 Data

Hrishikesh Keswani[1], Krishit Shah[2], Hritik Hassani[3], Moses Gadkar[4], Er. Manoj Kavedia[5]
[1, 2, 3, 4, 5]*Department of Electronics and Telecommunication, Thadomal Shahani Engineering College, Mumbai, India*

Abstract: ***During the COVID-19 pandemic, many data visualizations were created to alert the public to the rapidly growing threat. Statistics on the spread of COVID-19 have been displayed on data dashboards, a mechanism for sharing information throughout the pandemic, which has aided in this process. When developing the visuals for COVID-19, the majority of time was spent on the technical aspects of designing and evaluating various visualization methods. Little is understood about the inner workings of visualization production processes due to the complex sociotechnical environments in which they are embedded. However, such ecological data is necessary for identifying the particulars and tendencies of visualization design practices in the wild and generating insights into how artists learn to perceive and approach visualization design on their terms and for their contextual aims. We conducted in-depth interviews with dashboard designers from federal and state health departments, major news media outlets, and other firms that created (often widely used) COVID-19 dashboards to gain insight into the following areas. What kind of problems, disagreements, and conflicts arose during making the COVID-19 dashboard because of the participation of visualization creators? The trajectory of design practices—from genesis to expansion, maintenance, and termination—is determined by the complex interconnections between design goals, design tools and technologies, labour, emerging crisis circumstances, and public participation. We zeroed in on these procedures' tensions between designers and the general public. Conflicts frequently arose due to a chasm between public demands and prevailing policies. They typically centred on the types and amounts of information that should be visualized and how public perceptions shape and are shaped by visualization design. The strategies used to deal with (potential) misinterpretations and misuse of visualizations. Our findings and takeaways offer fresh viewpoints on visualization design by highlighting the bundled activities typically linked with human and nonhuman participation along the entire trajectory of design practice.***

Keywords: COVID-19, visualization, analyses, participation, big data

I. INTRODUCTION

During the COVID-19 pandemic, a set of visualizations called COVID-19 dashboards were developed to help manage the spread of this public health disaster. These dashboards included information on the number of cases, deaths, hospitalizations, tests, and vaccines. These visuals are vital for policymakers and public health organizations to make strategic decisions. They also disseminate information about the pandemic scenario to the wider public to affect people's routine choices and actions. Crisis information infrastructures (i.e., networks of diverse sociotechnical systems that facilitate information sharing during crises) have become increasingly dependent on visualizations like COVID-19 dashboards for the pandemic [76].

Although certain COVID-19 visualizations have been presented and evaluated in the literature [4, 6, 9, 19, 22, 35], the design processes employed by COVID-19 visualization producers have received relatively little attention. These procedures cover not only the visualization products themselves but also the design processes that went into making them and any difficulties or conflicts that developed. These COVID-19 visualizations could not have been made without many people's hard work and cooperation.

Management, epidemiologists, and data visualizers all chip in on dashboard designs [7]. Due to the pressing nature of the pandemic scenario and the complex nature of the teamwork required to develop these graphics, the designers may not have strictly adhered to the rules provided by visualization experts. This provides a unique opportunity to observe the creation of these crucial COVID-19 graphics "in the wild" (for instance, how technology is applied in the real world and in settings that mimic nature [17,51]). To be prepared for future crises and pandemics [24], it is crucial to learn from and synthesize earlier design approaches and experiences, such as COVID-19. Such a retrospective analysis of design practices is necessary to understand how individual’s approach and engage in visualization design processes daily, on their terms, and for their own goals.

Public-facing dashboards were crucial for disseminating data throughout the epidemic, and this research analyses the design choices used for COVID-19 visualizations. The hidden forces at work here will also become clear.

The work is guided by the following research questions (RQs):

To what extent did designers participate in creating the COVID-19 cockpit display?

What challenges were encountered during COVID-19 in the process of making these visuals?

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To get to the bottom of these questions, we conducted in-depth qualitative interviews with 26 individuals involved in developing COVID-19 dashboards. Organizations, including the federal government, state health departments [65], and the major media, were well represented at this meeting since they all helped maintain this critical information backbone. All the volunteer-made visualizations we have released so far during this pandemic have been extremely popular, averaging between tens of thousands and hundreds of millions of views each day.

Our qualitative and empirical study investigates the approaches to visualization design adopted in response to the public health emergency posed by the COVID-19 pandemic. Our studies center on the steps taken throughout visualization design procedures' creation, growth, upkeep, and final dissolution. The dynamic interplay between design goals defines phases, visualization methods and technologies, human effort, and audience input, how visualizations shape and are shaped by public perception, how designers cope with (possible) misunderstandings and misuse of visualizations, the tensions between public demands and long-standing policies about the type and quantity of information to be visualized, and so on.

II. BACKGROUND AND RELATED WORK

Below, we discuss the role of visualizations in crisis management and communication, as well as the findings from studies of visualization design methods

A. Visualization in Crisis Communication & Management

As a result of their growing importance in crisis management and communication, visualizations have become an integral part of catastrophe information architecture [12, 57, 76]. When linked together, these sociotechnical systems comprise what is known as "information infrastructures" [34]. Their accessibility characterizes them to users (no set definition of "user" in terms of the types and quantities of "users"), their integration of systems with different functions, and their dynamic evolution in response to pre-existing structures and norms [41]. In times of crisis, it is necessary to have access to reliable sources of information [74]. Visualization tools have helped emergency response organizations [31,33,44,69] educate the public on crises and threats. Real-time systems amid terrorist attacks [33] and simulation-based visualization tools amid prior pandemics [31,69] are two examples of such technology. Previous work [5,37,44,47,71] has also dealt with data visualizations of previous pandemic epidemics and other disasters like storms.

A growing body of literature [6,13,19,22,28] is devoted to designing and evaluating COVID-19 data visualizations. For instance, a survey study [75] analysed 668 COVID-19 data visualizations to create a landscape map of the existing visualizations. Their paper surveyed the landscape of signal visualization techniques, including methods for alerting users to the severity of COVID-19 and methods for predicting future trends. Other research [19,35,43,52] has examined the impact of visualizations on people's understanding and assessments of the dangers posed by modern pandemic scenarios. For instance, Li et al. [35] found that people's interpretations of maps improve when they are shown the same map in a series of images with different colours.

While there has been extensive study of the visual design of COVID-19 visualizations, surprisingly, little attention has been paid to the design methods employed by the designers, despite the complexity of the sociotechnical contexts in which these visualizations are used. Because of the lack of public information on the COVID-19 visualization design process, teams creating COVID-19 dashboards frequently promote blog entries as the only information [2]. Without knowing how these crucial images are made, researchers cannot take advantage of "success" and "failure" in visualization design or the challenges involved with these techniques in the wild. Errors and crises can be avoided in the future with the help of lessons learned from the past in the design process [1,58,73].

Despite earlier work offering advice on creating visualizations to benefit the general public in understanding information under non-crisis circumstances [35,38,56,66], little study has studied the relationship between public perceptions and visualization design during a crisis. Our research seeks to fill these gaps by expanding on prior work on visualizations in crisis communication by analysing design methodologies while also considering the socio-cultural-political contexts in which they are embedded.

B. Understanding Visualization Design Practices

We place our findings within the larger body of literature on design methods. Over the past decade, scholars interested in visualization have moved their focus from design studies to the design processes behind creating visualizations [29,40,45,46,53,64,68]. Visualization design studies are research projects in which researchers analyse a specific real-world problem encountered by domain experts, design a visualization system to aid in solving this problem, validate the design, and reflect on lessons learned to improve visualization design guidelines [54].

Compared to visualization design studies [32,45,60], work focused on design appears to be more diffuse, embedded, and long-term. For instance, Kang et al. [29] evaluated the visual analytics process using a longitudinal field study and provided research-based design recommendations for improvement.

Similarly, Tory et al. [64] examined the work practiced by dashboard users. They reframed them as "data conversations" (i.e., iterative exchanges between humans and data to ask and answer questions) to better fulfil these users' varying needs. How do designers and those who work in visualization interact, bearing in mind the complexities and contexts of design? This question was explored in recent studies by Parsons et al. [45,46]. According to Sadowski [53], corporate dashboards are abandoned due to interconnected organizational, cultural, and technical issues, such as new leadership and problems with automated updates, rendering the dashboards obsolete.

Existing research on design techniques suggests that the academic paradigms referred to as "best practices" may not always be appropriate in the real world. Significant issues are revealed by real-world design challenges, such as the lack of a logical framework to lead the design process [45], difficulty with tool switching while making visualizations [29,64], and inadequate support for collaboration [29]. Furthermore, these studies show that context is important [3,27,32], as both knowledge and design are socially situated. Attributing human behaviour to pre-existing practices and methods is insufficient [61, 62]. The situational context controls the design process, which includes obstacles, constraints, and problems that may be identified and addressed only after being encountered in practice [21].

There has been a lack of investigation into the role of design processes in creating visualizations during the COVID-19 public health crisis, which is intricately linked to a wide range of sociotechnical contexts. It is important to consider how the pandemic has affected the design process since doing so can provide light on the sociotechnical elements that should be considered when designing visualizations in complicated and rapidly changing environments. Therefore, these methods can aid in the discovery of more workable and effective strategies. Using what was learned throughout the process of making the COVID-19 dashboard can help us prevent similar disasters in the future. Our research is meant to fill those voids.

III.METHOD

This research analyses the guiding principles, constraints, and situations that informed the development of the COVID-19 dashboards. We conducted a qualitative interview study with 26 people in the US with the approval of the Institutional Review Board. (IRB). We could deeply understand the participants' lives, thoughts, and beliefs using a qualitative inquiry method.

A. Participant Recruitment and Overview

All contestants in the United States must be 18 years old, have fluent English speakers, and have created COVID-19 dashboards (or public-facing visualizations that convey COVID-19 data).

We used a wide range of methods to recruit participants. This study's original sample was drawn from a survey of 668 COVID-19 visualizations aimed at the general public [75] and featured in 158 news organizations across the United States. Our first step was to contact the 158 companies responsible for the COVID-19 visuals through email. In the email, we detailed the benefits and risks of participating and provided a consent form and payment details. Those in charge of developing COVID-19 dashboards were also urged to share details of our research with anyone who might be interested. When direct contact was not easily accessible, the snowball sampling approach [26] was invaluable. We made a concerted effort during recruitment to identify vital design personnel, targeting particular federal and state health departments.

We conducted 26 online interviews with participants between May and July.

July 2021. Federal agencies, state health departments, mainstream news media, non-profits, academic institutions, and new crowdsourced organizations created the federal government's COVID-19 data products [65]. Significant interest has been shown in the COVID-19 dashboards developed by our participants (e.g., up to hundreds of millions of website visits daily). Participants came from various backgrounds, including data journalists and a state health department director.

B. Semi-structured Interview Study Procedure

To better understand the COVID-19 dashboard design concepts, the research team developed a semi structured interview guide before beginning the study. There was a different guide for each interview, so we could ask more in-depth questions and get to the heart of the topic with each interviewee. Each interview guide was written by a different author, who interacted with the COVID-19 dashboard(s), read the documentation and user guide (if applicable, such as related publications and online articles), and jotted down notes on key questions to ask during the interview.

The following are some of the themes that will be discussed in the interview: Focusing on the process, people involved, tools and technologies, and evaluation of COVID-19 visualizations, this interview aims to: 1) place the participant's involvement in the crisis of COVID-19 in context; 2) understand the participant's design practices, decisions, and strategies; and 3) examine problems and difficulties specific to the COVID-19 crisis. The interview questions were tracked with those used in previous studies that examined the design process (as described in Sect. 2).

Every remote interview was conducted via Zoom (an online meeting tool). Interviewees were prompted to recall their earlier experiences in designing COVID-19 dashboards. Each interview lasted about 75 minutes on average, ranging from 60 to 110 minutes. The next step was for participants to answer some brief demographic questions via an online survey hosted on Qualtrics [48]. In exchange for their time and effort, qualifying participants were compensated with a $30 gift card at the study's conclusion.

IV. FINDINGS

Our study details the evolution of visual designers' workflows throughout the COVID-19 pandemic, from the inception of the dashboards (the creation phase) to the incorporation of new features to satisfy the needs of management and the public (the expansion phase) to the reduction in the cost of maintaining and updating the dashboards (the maintenance phase), and finally, to their conclusion (denoted as the termination phase). These approaches were affected by shifts in the overarching goals, visualization tools and technology, labour, public participation, and the rapidly evolving pandemic scenarios. Moreover, we talk about studies of the growing hostility and conflicts between visual artists and the broader public as the crisis develops. We also discuss the participants' positionality or how their different affiliations may inevitably lead to different perspectives and biases in their design methods.

A. *Shifting Practices: Creation, Expansion, Maintenance, and Termination*

1) *Creation Phase:* Our participants reported that creating COVID-19 visualizations for the general public was a top priority for their institutions in response to the unfolding crisis and to keep the public informed, given the rapid pace at which events were unfolding during this epidemic. Getting the apparatus going we found that the technologies firms opted to utilize to create COVID-19 dashboards were mostly decided by how well the tools fit inside the infrastructure that participants sought to develop for the business to reach their ultimate goal. P09 explained the following for choosing Microsoft Power BI: "We use Power BI because we transitioned to Office 365 last spring, and Power BI is embedded into that infrastructure. In addition to problems with team members' ability to access visualization tools and products, the proficiency of these products' developers affected how well they connected with the existing infrastructure. Due to the time constraints, they faced during the epidemic. Many designers said they "did not want to learn new things [technology] at this stage." However, our participants cautioned that the selected tools might not have been the ones each designer preferred. This was often the case while deciding on a visualization tool. Several criteria, such as the level of expertise among key design teams, the number of top-down decisions and leadership involved in the design decisions, and more, determined how well a tool integrated into the infrastructure.
2) *Expansion Phase:* After the first dashboard was made, the number of designers, stakeholders, and the general public interested in it grew unexpectedly rapidly. Because the pandemic was rapidly changing, everyone decided that the initial dashboards were not good enough. As more COVID-19 data was collected and the needs of organizational leadership and the general public expanded, so did the number of visualization features and functions. Examples include introducing features like the showing of disaggregated demographic data (e.g., by age, gender, race, and ethnicity) immediately after adding dashboard components indicating the type of COVID-19 testing data. As the public's needs expanded and the crisis continued, participants' responsibilities increased, and they were forced to work longer shifts to keep up (such as 60 hours or more per week). Furthermore, numerous "unexpected" failures directly resulted from the increasing demands (e.g., server jams and performance issues). The rapid growth of the team, the increasing need for more data and features, the spotlight these visualizations are bringing in, and the growing frequency of unexpected setbacks are all hallmarks of the expansion period. The crisis's unpredictability and changes in labor, public demand, and leadership significantly impacted the types and methods of visualizations developed.
3) *Aim:* A new overarching goal for organizations was to manage the shifting needs by showing more dimensions of COVID-19 data and improving visualization performance in light of the quickly evolving pandemic situation and demands from both leadership and the general public.

4) *Maintenance Phase:* We observed that the COVID-19 visualization design approaches later entered a maintenance phase. In light of this shift, the group opted to forego building any new infrastructure to maintain existing systems. Maintaining a precise definition of when this stage ends and the next is challenging. However, after 6-12 months following the initial releases of the COVID-19 dashboards, participants reported reaching a plateau regarding the labor and effort required in this phase. We highlight the significance of temporality in this change of procedure, mirrored in the prolonged length and enduring impacts of the epidemic. Goal: Design teams looked to reduce team size to cut down on the cost and effort of maintaining the COVID-19 dashboards.
5) *Labor:* During the servicing period, the total number of designers working on COVID-19 graphics was lowered by a small number of very large companies (n=3). Our respondents told us that the team's core members had remained the same. New technical possibilities are emerging. During the downtime, several promising new avenues for innovation opened up. Rather than manually examine data concerns at the outbreak's outset, organizations have used new technologies and visualization tactics, such as redesigning their visualization infrastructure and pipelines and obtaining human-in-the-loop strategies. For example, P07 mentioned that there were "many technological possibilities for us" and that "the pages would get reprinted several times a day, and it was a pretty major arduous job that is required." A hundred employees are doing different things, so we are trying to streamline the procedure. Because of this, we have spent the last few months building a new infrastructure that will allow us to maintain making this website for longer periods with fewer employees.
6) *Termination Phase:* To date, just two respondents have admitted to stopping dashboard maintenance and updates, while three are unsure when to pull the plug. This is the first step in winding down the visualization design practice. Since some dashboards relied on open-source software and publicly available data, failures occurred when these resources were no longer available. However, decisions to end employment were not always prompted by fear of the worse. According to our feedback, a company's decision to stop updating its resource-intensive products may indicate that its aims and motivations have been fulfilled. These points of view emphasize that it may not always be bad and should sometimes be viewed as a mark of "success" when updates and maintenance are discontinued. For example, P13, a crowdsourced team member contributing to the federal COVID-19 data products, said, "We wanted to wind down and point [the audiences] to the federal government as they should be the single source of truth for this kind of data." As one of the main reasons for stopping the production of COVID-19 data products, the P13 team's belief that "the data was excellent enough from the Federal Government that [they] do not [have to] [continue doing this]" was cited. These citations further highlight the need for less reputable sources to supply COVID-19 data in the context of the United States. Due to abundant information sources, people may become perplexed or distrustful of authorities [74]. The termination of dashboard updates was celebrated by some businesses but had a devastating effect on others. The need to consider several viewpoints when evaluating success measures is emphasized because different cultures have varying criteria for measuring the same variable.
7) *Finding the Right Metrics for Success:* Web traffic/views, total media coverage, number of "embeds" (if relevant), usability (i.e., visualizations work effectively throughout the epidemic), and clarity were cited as examples of traditional measures used by participants to evaluate the performance of COVID-19 visualizations (e.g., fewer clarification questions). These standards were similar to those used in academia [50, 55]. However, we did find that the number of "angry people" was a "unique" element in influencing the "success" of visualizations. P04, who worked in the state's public health department, told us, for example, that "the lack of irate people was the measure of achievements... Unfortunately, a flood of really unfavorable feedback from the public came in after they thought they were not getting what they needed.

B. Conflicts between VIS Designers and General Public

Designers and the general audience have disagreements and diverse opinions over visualization design strategies. The COVID-19 situation has created unprecedented stress and uncertainty, and existing laws and procedures have only exacerbated these already fraught relationships. By taking a closer look at these points of contention, we can see that the visualizations presented at COVID-19 are the product of debates between designers, the general public/audiences, and preexisting policies.

C. Participant's Positionality Regarding Design Practices

Most of the information and lessons learned and offered by our participants are subjective. Thus, it is vital to evaluate how their professional backgrounds, affiliations, and ideals may have influenced the creation of COVID-19 graphics. Below, we present the general tendencies in the participants' positionality about their design approaches.

Accept humanity and compassion: Regardless of their place of employment, nearly all participants reported being "very thoughtful and considerate" while building the dashboards. Participants stressed the need not to dismiss the information as "printing numbers," but rather keep in mind that "a number is a person who has grown sick and died." Designers, particularly during a pandemic, should make this concept of empathy and sympathy a top focus when making visualizations.

Controversial and political depictions One would assume that visualizations are inherently political and biased, as Winner would argue [72]. Thus, one theory proposes that visualizations are (consciously or subconsciously) generated and deployed to serve particular societal objectives [30], particularly in the context of the politically controversial COVID-19 epidemic. Our participants insisted it was "not a political matter" because their dashboard design approach was consistent with their overall "neutral" design philosophy. Those working on the COVID-19 dashboards who had ties to the government said they felt extra pressure because "in the present American climate, the government isn't often seen in the best positive manner." Tensions, including public criticism, misunderstanding, and mistrust, left several participants "frustrated or weary," they told us.

Furthermore, despite popular perceptions of media bias and overall mistrust of the media during COVID-19, three out of four people employed by mainstream media reported attempting to explain the COVID-19 data through "simple and bare-bones" visualizations [67]. Despite our best efforts, not one of our participants could spot the engaging and intended tales, but that does not mean they did not overlook some supplementary information while designing. Our research shows, for instance, that just plotting "as is" data leads to more prejudice and stigma (see Sect. 4.2.2). Audiences may take visuals at face value, interpreting their message as "data fact" or "the truth." On the other hand, such foresight may not hold water in the real world. A wide range of regional constraints and opportunities: However, there are noticeable differences between people's habits. Designs are determined by the availability of resources, including money, people, public health knowledge, and visualization technology, as well as the complexity of bureaucratic conflicts and limitations on their methods. These factors operate as both "enablers" and "constraints" in the design process at a local level. Participants affiliated with government agencies or state health departments were subject to additional regulations, such as HIPPA and the Americans with Disabilities Act (ADA) [14]. While all COVID-19 visualizers were required to adhere to these principles, the extent to which each designer did so and how they were perceived varied widely. The flexible and user-friendly visualizations these standards provide may also be valuable to wider audiences (e.g., those with color vision deficiencies)

V. DISCUSSION

Based on our findings, we discuss the moral dilemmas that arise and offer recommendations for future research into the visualization design process.

A. Shifting Attention to Visualization Design Practices

The first wave of visualization research focused on architectural models, the second on design studies, and the third, or "practice paradigm," is interested in comprehending design practices that involve the interconnected and interwoven nature of tools, technical systems, organizational structures, social and political contexts, [25, 32]. Researchers have found a paradigm shift in visualization studies [45]. However, the VIS community has not widely accepted this broader view and incorporation into design processes [45]. Our research attempts to fill this gap and provides useful information for COVID-19's exploration of real-world visualization design strategies.

We found Phase shifts is important to examine the concept of "shifts" because time is so important when trying to make sense of design practices. As a result of shifts in design's overarching goals, tasks, labor, tools, and sociocultural and political contexts, it will be necessary to adapt current visualization methods and develop new ones to address these shifts adequately. Paying attention to these shifts in behavior can help us foresee how future visualization design methods may differ from those we use now. We might be able to lessen the chances of future disasters if we do this. In times of crisis, the evolution of visual design processes necessitates new types of visualization research to identify opportunities and problems.

Perceptions of "designers" are shifting. During the COVID-19 dashboard design process, the nature and number of "designers" went through rapid and unpredictable shifts. Due to a rise in the number of designers, many different approaches were taken (for example, hiring people from different backgrounds), leading to a general lack of cohesion in the field (e.g., color schemes, choice of maps). Public perception and trust in design firms may suffer due to methodological inconsistencies [74]. As a first step toward fixing the problems brought on by the expanding definition of "designers," researchers must examine how design tools support onboarding activities to effectively aid newcomers with getting started with design, especially under time pressure and stress. A unified design process is made possible by a solid onboarding process.

This concept of designers is constantly changing, and future studies should investigate how this affects, directs, and controls the design process. By fixing this problem, future design methods will be more usable and trustworthy, especially in times of crisis and teams with high member turnover.

Resources for Parallelizing and Relocating. Previous research has also shown that transferring between visualization tools is common practice [64]. However, it may be less common to create (nearly) identical visualizations using different tools simultaneously. We view concurrent visualization development as a risk-mitigation strategy that ensures peak performance while prioritizing core functionality. Based on these findings, service providers (like Tableau and Microsoft Power BI) will need to keep working to improve solution performance and accessibility. In addition, designers and company management should be conscious of the tools' limitations over the long run, anticipate the possibility of parallel work being necessary, particularly in dynamic and uncertain situations, and eventually switch to "sustainable" visualization techniques. Shifting dynamics between the public, designers, and government officials. Our findings suggest that the ongoing dialogue between human actors, stakeholders, who may have conflicting viewpoints, and nonhuman actors, like existing laws and regulations, is transforming COVID-19 visualizations into border objects. By shifting our focus to visualizations as border objects, we can gain a new perspective on their design—specifically, on how experts from different fields can work together to facilitate understanding across disciplines, improve decision- and policy-making, and ultimately benefit from the data at hand. In times of crisis, visualizations are seen as border objects, making their "plasticity" [59] and adaptability crucial. In a nutshell, during a crisis, visualizations should be flexible enough to meet the needs of different regions and groups of stakeholders while being robust enough to reach a common goal.

B. Towards Responsible Visualization Practices

More and more people, inside and outside the VIS community, are thinking about ethical challenges in design [15,16,39]. Our contributions to this body of knowledge include empirical data that probes the hidden motivations and ethical conundrums behind the COVID-19 visualization design processes. Some considerations to consider when implementing ethical visualization design methods are discussed below.

Acquiring a keen understanding of your data is essential when working with visualizations. In the context of this research, "data awareness" means fully grasping the implications of the data. This data awareness extends past the familiar data type and abstraction [42] that researchers in the visualization field are accustomed to. Instead, it is confined to that one setting. The importance of leveraging public health professionals and GIS specialists' domain expertise to achieve this data awareness was emphasized by our participants. In a public health emergency, the potential for visualizations to be misinterpreted and misused is heightened by a lack of topic expertise. In light of this, we argue that just because visualizations could be made for almost anything does not mean they necessarily should. Carefully consider how your visuals will be received. Researchers in the visualization field may want to incorporate an awareness of positionality into future academic and applied projects. This will help designers become more self-aware of how their hidden biases may affect their design processes. It will also encourage transparency on the limitations of design work to audiences.

Misunderstanding and misuse are two common problems that should be considered during the design phase. Since visualizations are so widespread, some of them will inevitably be misunderstood or used incorrectly [20]. Several measures, such as providing audiences with contextual information and methodology, could assist in reducing these risks, even though fundamentally addressing these misunderstandings and misuse-related outcomes is challenging. To prevent further misinterpretation and misuse of visualizations, we suggest incorporating this issue into the design goals of future work. We argue that "unintended effects" may be detrimental to certain communities, so extra caution must be used when creating visualizations of racial inequalities, discrimination, and health disparities. Many groups, purportedly in the name of "social good," used COVID-19 data visualization to investigate the pandemic's impact.

Nonetheless, our research shows that visualizations may have contributed to the disproportionate marginalization of some groups. These "unintended consequences" may have exacerbated larger societal issues that inspired design decisions. Visualization designers should put a premium on considering the implications of their work and creating visuals that are as clear as possible. Instead of "superficially" displaying the data "as is," we should investigate "how they may become" and why they become what they are with and through visualizations. Therefore, we encourage future research to investigate how visualizations may be created and shared in a way that, if possible, addresses unfairness, as this is currently an unanswered subject. To understand the social impact of visualizations, it is necessary first to investigate this issue.

VI. LIMITATIONS

Our study has limitations due to the sampling methods we employed; we were only able to collect data from U.S. design firms. We suggest that future studies investigate the design processes of various visualization types with larger sample sizes and designers from non-western countries (e.g., visualizations that mimic infection and model parameters and visualizations utilized internally). Given the importance of temporality in understanding design practices, future research should continue examining the phase of practice termination after the pandemic is over and the long-term effects of policy changes on visualization design in practice. The role of different team members in the decision-making processes involving data-related policies is another area that could benefit from further study, as is the connection between the demise of visualization design approaches and the existence of various competitors.

VII. CONCLUSIONS

Regarding the broader sociotechnical issues at play here, our work contributes to the preliminary investigation into the design strategies behind the development of COVID-19 visualizations, which are an essential part of the crisis information infrastructure. As a result of this work, we will better understand how to visualize new situations and evolving environments. We encourage the visualization community to fully document the design principles involved in the expansion, maintenance, and termination stages, as opposed to the norm in design culture, which focuses on producing new graphics. Changes in the specific contexts in which these activities took place, and the interconnected relationships among labor, broad objectives, tools and technologies, and public participation shaped the design strategies employed. We recommend that future research examine the overall trajectory of visualization design techniques while also considering the ethical concerns raised by these behaviors.

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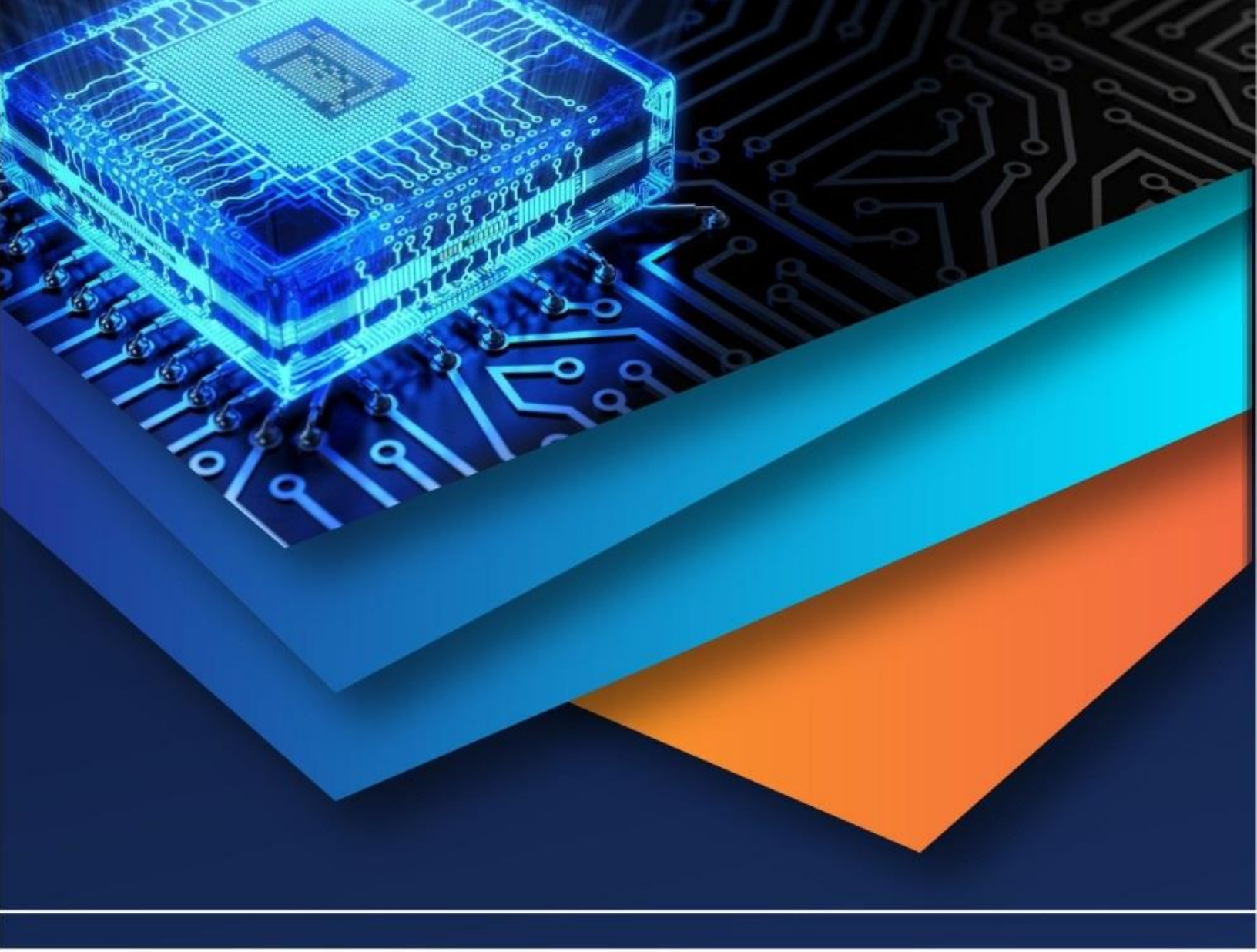

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