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Article

Design for Emergency: How Digital Technologies Enabled an Open Design Platform to Respond to COVID-19

Sara Colombo [1], Estefania Ciliotta [2,*], Lucia Marengo[3], Houjiang Liu[4], Piero Molino[5] and Paolo Ciuccarelli[2]

[1]Faculty of Industrial Design Engineering, Delft University of Technology, Landbergstraat 15, 2628 CE Delft, The Netherlands
[2]Center for Design, CAMD, Northeastern University, 180 Ryder Hall, 360 Huntington Ave, Boston, MA, 02115, USA
[3]DocPlanner, Carrer de Josep Pla, 2, Barcelona, Catalonia 08019, Spain
[4]School of Information, The University of Texas at Austin, 1616 Guadalupe St., Austin, TX, 78701, USA
[5]Predibase, 1190 Mission St. Apt 516 San Francisco, CA, 94103, USA
*Corresponding author: e.ciliottachehade@northeastern.edu

Abstract

In the COVID-19 pandemic, digital technologies (DT) supported the design and implementation of solutions addressing new needs and living conditions. We describe Design for Emergency, a digital open design platform developed to ideate solutions for people's fast-changing needs in the pandemic, to analyze how DT can affect human-centered design processes during emergencies. We illustrate how DT: i) helped quickly collect and analyse people's needs in different countries, visualize such data, and identify design directions and problem spaces; ii) facilitated the creation of a virtual network of stakeholders and an open-innovation digital platform; iii) inspired the ideation of solutions responding to people's changing needs and affected their implementation. We discuss the implications of adopting DT in designing for and during emergencies, as well as their current and future potential to promptly respond to emergency situations through a human-centered approach.

RESEARCH HIGHLIGHTS

- A case study of a digital open design platform, Design for Emergency, is used to investigate how digital technologies can affect human-centered design processes during emergencies such as the COVID-19 pandemic.
- Digital technologies can quicken the identification and visualization of emerging user needs and design spaces during emergencies, in different geographical contexts.
- Digital technologies can support the creation of global networks of stakeholders through remote, open, and decentralized collaboration.
- Digital technologies facilitate open design paradigms, which accelerate impact, in situations of emergency.
- Limitations of digital technologies include lack of inclusivity in the identification of user needs, the need for human fine-tuning and interventions in data analysis and visualization, and the risk to hinder the implementation of ideas.
- Advanced digital technologies may be used to increase the engagement of designers and stakeholders in open design platforms for emergencies and to automate the creation of digital solutions to accelerate ideas implementation and social impact.

Keywords: human–computer interaction; open design platform; digital technology; data visualization; COVID-19 emergency response; human-centered design

1. INTRODUCTION

In the past few years, digital and computing technologies have deeply transformed the way we live, relate to each other and work, with the COVID-19 pandemic accelerating and reinforcing some trends that had started long before its dramatic advent. Some of these new trends—e.g. remote working, industry digital transformation, online social interactions—will likely become defining features of today's and future society. In this work, we explore a particular opportunity provided by digital technologies during the pandemic: the possibility to remotely collaborate in a situation of emergency to design and develop solutions addressing people's needs. We do so by analysing how digital technologies enabled the creation and development of Design for Emergency (DfE), a global initiative to develop human-centered solutions addressing social issues caused, or uncovered, by the COVID-19 pandemic.

DfE[1] is a global online platform for sharing open solutions addressing people's needs in situations of emergency. The platform was launched during the COVID-19 first lockdown in the western world, specifically in Italy, in March 2020. Its main goal was to understand people's living conditions, needs and feelings during the lockdown, in order to rapidly develop products and services that could address that new, unexpected reality.

The DfE initiative was built, launched and performed completely online, by a team of volunteer researchers and profession-

[1] https://designforemergency.com/

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als who were located in different areas of the world and started to collaborate for the first time on this initiative. After 2 years, the core team is still fully remote and keeps cooperating on this project, although with different levels of involvement.

DfE could not have been realized without the ubiquitous spread and accessibility of digital technologies. Although online collaboration became a reality during the pandemic, the nature of DfE is profoundly different from the kind of virtual collaboration that millions of coworkers worldwide experienced during lockdowns, as well as from the experience of joining strangers in short virtual initiatives, projects, or design challenges or hackathons. DfE is an example of a long-term collaborative initiative that was launched during an emergency, involved global partners and stakeholders with no collaboration history and was developed by a core team that cooperated for 2 years in different time zones. This initiative features the involvement of thousands of people in online surveys, hundreds of designers participating in virtual design challenges and dozens of research and project partners in 12 countries. The magnitude and impact of this initiative would be unthinkable in a different moment in history and is the result of a number of different computing technologies being available, accessible and adopted concurrently.

In this paper, we present DfE as a case study to describe and reflect on how state-of-the art digital technologies provided essential tools to intervene in the COVID-19 pandemic through an open design platform addressing emerging and novel user needs. We discuss the potentials and limits of such technologies and possible future applications in situations of emergency. We believe the development of DfE helps to pave the way for a deeper reflection on the opportunities provided by technologies to increase societal resilience to different kinds of crises and emergencies.

2. RELATED WORK

In this section, we first survey both benefits and challenges of adopting digital technologies for remote digital collaboration during the COVID-19 pandemic and review specific initiatives. Subsequently, we discuss the importance of studying user needs in the design of crisis and emergency management and point out the lack of social and technical infrastructures that help to collect diverse user needs in a remote context. We introduce *meta-design* as a valuable framework that guided us in the creation of the DfE platform, as a digital remote collaboration initiative to address a global design question: in the context of COVID-19, how could designers design for remote users whose needs and situations were unknown and continuously changing?

2.1. The use of digital technologies for remote collaborations during COVID-19

During the early outbreak of COVID-19, digital technologies, such as the internet of things (IoT), artificial intelligence (AI), big data and blockchain, are heavily adopted to monitor, mitigate and prevent the spread (Ting *et al.*, 2020; Juul *et al.*, 2021; Yang *et al.*, 2021). Moreover, digital services designed for contactless experiences, such as telehealth nursing, contactless payment and dining in robot-serviced hotels and restaurants, are being increasingly accepted by people as a protective measure (Andrews *et al.*, 2020; Kim *et al.*, 2021). These digital technologies not only tremendously facilitate clinical and healthcare practices but also benefit every aspect of social life and community.

Remote collaboration is one of many practices that benefit from these digital technologies to help people back to the new normal. For example, students use Live streaming and Massive Open Online Courses (MOOCs) for 'distance learning from home' (Chen *et al.*, 2021). With the aid of video conferencing and telecommunications, isolated older adults are also reconnected with medical specialists to receive remote nursing assessments (Liu *et al.*, 2022). Scholars in human–computer interaction (HCI) and computer-supported cooperative work (CSCW) envisioned long before that remote collaboration in distance would finally come true on a larger scale with the help of digital technologies (Olson and Olson, 2013, 2014). Due to the outbreak of COVID-19, both the individual and organizational levels accelerate the use of these digital technologies for remote collaborations (Branscombe, 2020; Fernandez *et al.*, 2020).

Specific remote collaborations are also initiated as responses to the COVID-19 emergency. For example, researchers in epidemiology initiate a COVID-19 NMA platform[2]. It collects clinical trials about treatments and vaccines, provides standardized methods to assess the quality of trials' methodologies and publishes weekly systematic reviews (Juul *et al.*, 2021). Esri, a geographic information system company, launches a new hub that provides map resources and geographic analytical tools for researchers to track the spread of COVID-19 (Dong *et al.*, 2020; Pratt, 2020). At the same time, the international fact-checking network initiates the #CoronoVirusFacts alliance that united fact checkers around the world to fight the COVID-19 infodemic (Poynter, 2020).

However, different from these collaborative projects that aim to provide specialized digital resources and tools to a specific domain, only a few of them target gathering and analysing diverse needs of the public, including both normal people and more vulnerable communities, such as the older adults and people with disabilities. Note that from various studies on vulnerable communities during the pandemic, important voices are being heard by researchers, showing greater sufferings than we thought for these communities (Hunsaker and Hargittai, 2018; Kim and Choudhury, 2020; Liu *et al.*, 2022; Suhaimi *et al.*, 2022). For example, the traditional QR codes lack a tactile 'cue', or 'audio prompt' for visually impaired people to use. Not all public spaces provide accessible technology such as screen readers for blind people in a socially distancing world (Holloway *et al.*, 2020). Additionally, domestic violence survivors are locked down with abusers, lacking sufficient legal support (Kim *et al.*, 2022). Goggin and Ellis (2020) summarize that most of these people's needs are little reporting of concerns for their experience during the pandemic. IDEO, a global design agency, organizes several COVID-19–related challenges that aim to collect experiences from local communities, inspiring businesses for design innovations. However, it does not provide any shared resources, database or solutions as a return. There is a lack of digital infrastructure to remotely and collectively gather information from normal people and vulnerable communities, further hindering immediate innovations that could have helped to address new challenges brought by the emergency.

2.2. The importance of user engagement for innovating emergency response

Researchers have long been studying people's needs during the emergency and their needs for how the crisis should be managed. On the one hand, knowing how people respond to potential social emergencies, such as terror attacks, earthquakes and pandemic, help crisis managers to better design training programs or technological supports to enhance community resilience (Magnusson *et al.*, 2018; Suhaimi *et al.*, 2022). On the other hand, collecting diverse needs from different stakeholders also improves societal

[2] COVID.nma

collaborations and policy innovations, ranging from policy planning for both governments and industries (Hao *et al.*, 2020; Sharma *et al.*, 2022) to the development of new emergency technology for people (Ardito *et al.*, 2021).

The design community also thrives to facilitate the development of various emergency technologies, in particular by bringing user voices to the providers of emergency response services (e.g. governments, communal support organizations and other stakeholders). Design practitioners and researchers conduct participatory and co-design workshops (Lundberg *et al.*, 2012; Petersen *et al.*, 2015), user-centered ethnography, interviews and focus groups (Searle, 2010) to gather people's insights and experiences for collaborative innovations.

While emergency technologies, such as decision-support systems (Javed *et al.*, 2010), crisis monitoring platforms (Herranz *et al.*, 2012) and disaster assistant tools (Al-Sadi *et al.*, 2023) remain of major research and development interests, researchers also argue for the need of building digital infrastructure and data repositories to collect, store and manage crisis-related information (Nguyen *et al.*, 2021). People's risk perception, vulnerability and their exposed value are parts of this key information for building community resilience.

In the case of the COVID-19 emergency, the above in-person user studies became impossible to perform, due to the lockdown enforcement. In the very initial stages of the pandemic, relevant stakeholder groups, including social organizations for crisis and disaster management, design, research and development communities, were all isolated, unable to identify first-hand challenges faced by people affected by the emergency. Although the flourishing social media platforms and online groups shared information about people's attitudes and behaviors as responses to the pandemic, there was a lack of systematic information processing pipeline that could distill, manage and store valuable user data to emergency service providers.

2.3. *Meta-design* and *open* innovation to address uncertainty and complex issues

During the COVID-19 emergency, people were facing unbridled uncertainty due to the surge of virus variants and dynamic protective plans (e.g. zero-covid[3] and stepped-up covid[4]). As most health specialists and policymakers point out, the uncertainty caused by the global pandemic has imposed a necessary burden on our society to hold and live under reality without knowing a possible future (Koffman *et al.*, 2020). Addressing such uncertainty through design, by generating solutions that could help people and communities be resilient during the lockdown and recover afterwards, required to adopt newer approaches than the ones traditionally employed in craftsmanship and user-centered design. Indeed, we needed to face the complexity and uncertainty of a global design problem brought by the pandemic: how could designers design for remote users whose needs and situations were unknown, unprecedented and continuously changing? We chose to adopt *meta-design* as a framework and mindset to experiment with new ways of implementing novel design practices in situations of deep uncertainty and in unknown and changing design contexts.

Although the concept of meta-design is still in its infancy (Nold, 2022), we adopt the definition proposed by Fischer and Giaccardi (2006), who describe it as: '*defining and creating social and technical infrastructures in which new forms of collaborative design can take place.*' Because this design concept reflects the needs described above about the lack of digital infrastructure and data repositories to collect, store and manage crisis-related information, we consider it as a valuable framework to guide the DfE initiative. It encouraged us to open up solution spaces and foster opportunities for others to design, by providing new infrastructures to remake the design process (Fischer and Scharff, 2000; Giaccardi and Fischer, 2008).

The design of the DfE digital platform represents our attempt to build a technical and social infrastructure to empower users and designers and give them the necessary autonomy to create global and local solutions in the context of COVID-19. The meta-design concept is visible in two critical aspects of DfE. First, the collective identification and sharing of people's needs and feelings to inspire initial seed ideas of emergency response solutions. Second, the facilitation of remote relational connections with different stakeholder groups to further develop those seed ideas. Both aspects are grounded in an *open* approach that guided the initiative since its inception. *Open* here is both in the sense of a feature of all the knowledge produced along the process—from survey results to solution templates, all outcomes have been published under a CC license—and as an inclusive, collaborative paradigm for innovation that could forge communities, rooted in the principles of the Open Source movement in software development (Ciuccarelli, 2008). Moving from individuals to communities also collaborates in addressing the complexity of the issues we wanted to face: 'the complexity of design problems requires communities rather than individuals to address, frame and solve them' (Fischer, 2004).

To enable that open approach and support creativity as a collaborative, knowledge-intensive, process (Ciuccarelli and Valsecchi, 2007), the DfE initiative has been conceptualized and implemented at three different levels: as a technological infrastructure for sharing data and information through the interactions between different stakeholders; as an horizontal, interconnected, organizational paradigm; and as a plural epistemological framework, which emphasizes sharing and propagation through a systemic approach to knowledge production, where coordination of resources is as important as individual contributions (Rullani, 2004). While the open approach proved to be effective during peak phases of the process, when understanding and acting—doing—where essential, more direction seems to be needed for keeping the community alive, once the main act of designing has been performed.

3. CREATING AN OPEN DESIGN PLATFORM BY LEVERAGING DIGITAL TECHNOLOGIES

In this section, we describe the open design platform—DfE—on how the project came to be and how we employed and adapted digital technologies in support of the initiative throughout all design phases. We also describe the impact of digital technologies on our team collaborations, the facilitation of open innovation paradigms and the inspiration, dissemination and implementation of ideas. More importantly, because design is a conversation with the situation—the context in which we design (Schon, 1984), *reflection* is particularly important in design research, interaction design (Zimmerman *et al.*, 2007) and design collaborations (Seravalli *et al.*, 2022). We present our *reflections* at the end of each design phase to critically analyse the *meta-design* and the *open* innovation approaches, as well as highlighting the relations between design processes, digital technologies and new collab-

[3] Llupià, A., I. Rodríguez-Giralt, A. Fité, and L. Lola Álamo. 2020. 'What Is a zero—COVID Strategy and How Can It Help Us Minimise the Impact of the Pandemic.' *COVID-19 & Response*.

[4] 'COVID-19 Pandemic in Boston.' Wikipedia. Accessed March 31, 2023. https://en.wikipedia.org/wiki/COVID-19_pandemic_in_Boston

orative practices that such technologies enable in situations of emergency.

3.1. Initiating DfE as an open design platform

When the World Health Organization (WHO) declared the COVID-19 outbreak a pandemic, on 11 March 2020, organizations, such as the World Bank[5], UN[6]—including designers and design agencies, such as IDEO[7]—quickly reacted, addressing the needs of hospitals and care facilities overwhelmed by patients in need of intensive care. Evidence was also growing about the unprecedented condition of isolation imposed on millions of citizens through restrictions in several countries: an unknown circumstance both for the people impacted and for the organizations and the institutions in charge to face it. At that time, Italy was the most affected country and no clear solution, nor a plan were available to address that condition. This gap in terms of knowledge and solutions about the psychological and social broader impact of the pandemic, triggered the launch of the DfE initiative, defined as: 'a design-driven reaction to the wickedness of the issues we were witnessing and to the lack of available solutions to cope with the social consequences of an unexpected and abrupt condition of isolation' (Colombo and Ciuccarelli, 2020). Starting from Italy, the initiative spread to other 11 countries, thanks to a spontaneous network of collaborators and partner institutions.

The DfE platform was conceived and designed as an open platform that enables and supports the creation of design solutions to benefit people's safety, well-being and social interactions during confinement measures due to the COVID-19 emergency. The platform has been progressively built on two pillars and two stages each. The *learning* phase (pillar 1) was aimed at understanding the unprecedented condition of isolation, and it was articulated in two stages: a survey to collect data (Stage 1) and data analysis and visualization (Stage 2). The insights built through the analysis were used to orient the *action* phase (Pillar 2), articulated in a series of open design challenges, calls and planned workshops with both partner institutions and professional organizations (stage 3). Acknowledging the urgency of providing concrete solutions, a fourth stage—implementation—was added as part of the action phase, to foster the development of the ideas collected through the design challenges into real solutions addressing the emerging needs.

The DfE initiative was enabled by digital technologies, which made it possible to 1) collect and analyse people needs during the pandemic in various parts of the globe; 2) remotely collaborate on a global scale with researchers, designers, local organizations and different stakeholders; and 3) inspire the ideation of seed solutions to address the social issues that emerged in different areas and disseminate them. The following subsections explore and discuss these three different roles in depth.

3.2. Identifying people needs through digital surveys and AI

The first area of investigation refers to the analysis of data collected through online user surveys. Data contain both quantitative and qualitative responses and was collected through an open-ended questionnaire designed and shared to participants around the world to complete. During our initial outreach, we collected answers to our questionnaires that involved both closed and open-form fields. The closed-form fields collected statistical information to group and slice the population of respondents (i.e. age group, their geographical location and other socio-economic indicators). Open form fields, on the other hand, collected answers in the form of short texts. The answers to these questionnaires were beyond expectations, and due to the open-endedness of the survey and the high volume of responses (1600 just in Italy, over 1 week), the researchers had some challenges in the data collection and analysis. In order to analyse the responses to questions like: 'what do you miss the most?' or 'what makes you feel good right now?', an in-depth qualitative analysis was needed to identify relevant keywords, concepts, or main topics.

We explored traditional qualitative research methods for the analysis of text-based responses; however, they did not meet the need to rapidly draw results. Therefore, we decided to adopt Natural Language Processing (NLP) tools. Three experts in machine learning (ML) and HCI helped us test different NLP tools to suit our needs. We experimented with several technologies from the fields of NLP and text mining. In order to iterate quickly and cheaply, we decided to adopt robust open-source technologies. We built custom scripts for text analysis that used open-source tools to process text and analyse word and n-grams distributions and used scikit-learn (Pedregosa *et al.*, 2011) to identify topics using the LDA algorithm (Blei *et al.*, 2003), which identifies statistically a distribution of topics in each text snippet and describes the topic themselves as a distribution of words appearing in the texts. We also created topic and sentiment classifiers using fasttext (Bojanowski *et al.*, 2017) word embeddings and the Ludwig (Molino *et al.*, 2019) declarative deep learning framework. The intent of those classifiers was to identify if texts from the open fields belonged to some topics we manually defined through groups of words, and if the pieces of text conveyed a positive or negative sentiment. The open-source nature of all these tools was key in the iteration process and allowed us to experiment and compare quickly different solutions and adopt the ones that more closely matched our analysis needs.

Finally, the tool we adopted for extracting keyphrases from the answers to the questionnaire was Keyphrase Digger (KD) (Moretti *et al.*, 2016), which allowed us to obtain multi-word keyphrases across multiple languages ranked by a score that combines both word and n-grams statistical measures with informative patterns of parts of speech. In addition, the KD tool gave us the flexibility to develop and adapt to include additional languages. This feature was extremely useful because the project expanded rapidly to different countries. This tool helped us identify 100 key concepts distilled from participants' responses (n-grams of different lengths) associated with each question which were selected and manually clustered into broader topics.

The insights obtained from this set of text analytics tools were ultimately visualized in a web-based interactive interface built using D3.js (Bostock *et al.*, 2011), a library for building visualizations programmatically. Data visualization played two distinct yet interweaved critical roles in the project: first, it served as an internal tool to get a sense of the data collected and assess the analysis processes; then, it proved to be an effective communication tool, to both share insights with the designers involved in the design challenges and to provide meaningful pictures for dissemination through public media. Being able

[5] 'Task Force on Covid-19 Vaccines, Therapeutics, and Diagnostics.' World Bank. Accessed March 31, 2023. https://www.covid19taskforce.com/en/programs/task-force-on-covid-19-vaccines.

[6] United Nations. 'Coronavirus | Recover Better | United Nations.' United Nations. Accessed March 31, 2023. https://www.un.org/en/coronavirus/recoverbetter.

[7] 'COVID-19 Communication Inspiration Challenge.' Accessed March 31, 2023. https://www.openideo.com/challenge-briefs/covid19-communication-challenge

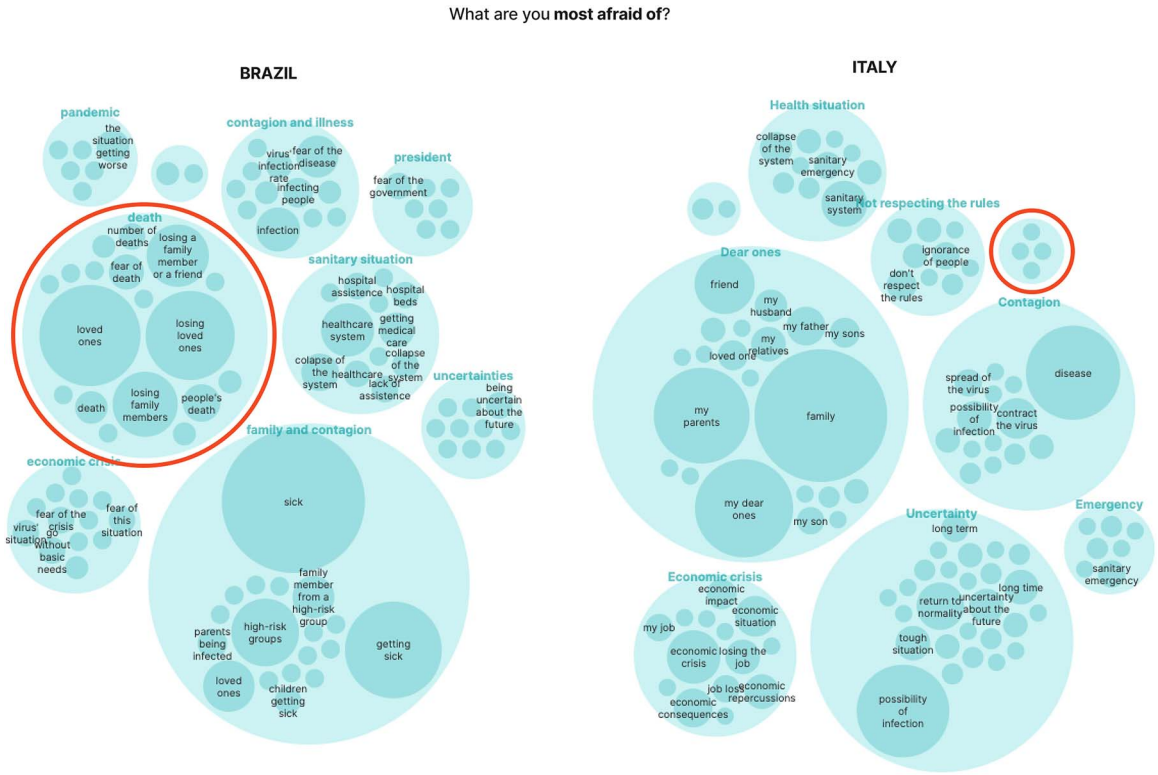

FIGURE 1. A visual comparison between survey responses from Brazil and Italy.

to visualize text analysis' results has been especially relevant, as it allowed us to quickly discover tokenization, lemmatization and key-phrase ranking issues, enabling a positive iterative feedback loop between text analysis algorithms and visualizations.

In addition to simple statistical charts (e.g. bar charts and pie charts) to describe demographic data, more complex visual patterns have been used to convey the relationships between concepts and keywords extracted through the NLP processes: interactive circle packing visualizations are effective in providing both an overview for hierarchical data sets and a zoom-in/out movement (Wang *et al.*, 2006). In Figure 1, a visual comparison between surveys reveals how a concept might be articulated very differently according to the context: this clearly shows how the cluster of terms related to 'death' is significantly bigger and more nuanced in Brazil than in Italy—two countries where a similar number of responses has been collected. Results were clustered into five main sections, to guide designers in the interpretation of users' experiences around five major topics: problems and needs, emotions, desires, motivations and time.

Given the scope of the initiative, designers were the primary target of our visualizations, but it became clear as the initiative unfolded that granting access to both the data and the visualizations to a broader public, from journalists to citizens, would provide additional value and potentially trigger other initiatives. In Figure 2, simple static bar charts have been assembled applying the small multiples technique (Tufte, 1990) in order to complement an article about our open design platform, written by a journalist for 'Corriere della Sera'—one of the most diffused newspapers in Italy. The visualization appeared both on the printed and the online version of the newspaper, showing how different age categories responded to questions about emotions and issues experienced during the pandemic.

All data visualizations are available on the DfE data platform[8]. The platform allows access to the full datasets for further analysis, following a fully open-data, open-source approach.

3.2.1. *Reflection*

Despite there are benefits of using these technologies to analyse vast amounts of text, manual intervention is still required, e.g. to categorize keywords into topics, in order to make results more accessible and useful to designers, or to adjust the translation of analysis results into English, to make them comparable between different countries. On these tasks, the AI technologies we adopted could not provide the quality needed (e.g. translations were not accurate, emerging topics were too broad, unclear, or not relevant to the purpose of the analysis).

Another limit was the need to adapt the KD tool to different languages, as just a few vocabularies were implemented in the original version. We encouraged our global research partners to collaborate with local experts who could provide support on these tasks, in order to analyse text in their own language. However, for many of them, this was an obstacle to the analysis of the open-text responses and their subsequent visualizations. For this reason, the final platform now features complete data visualizations only for a subset of countries (Italy, USA and Brazil).

It was clear to the authors that decentralizing this aspect of the initiative did not work for all partners, where computer science or NLP expertise working on the algorithms and codes was easily accessible, e.g. through cooperation with research teams in the same university, partners were able to perform the task. In other cases, support from the core team was expected, which however was not possible to provide, given the limited resources and the number of different tasks that needed to be managed by a very

[8] https://data.designforemergency.com/

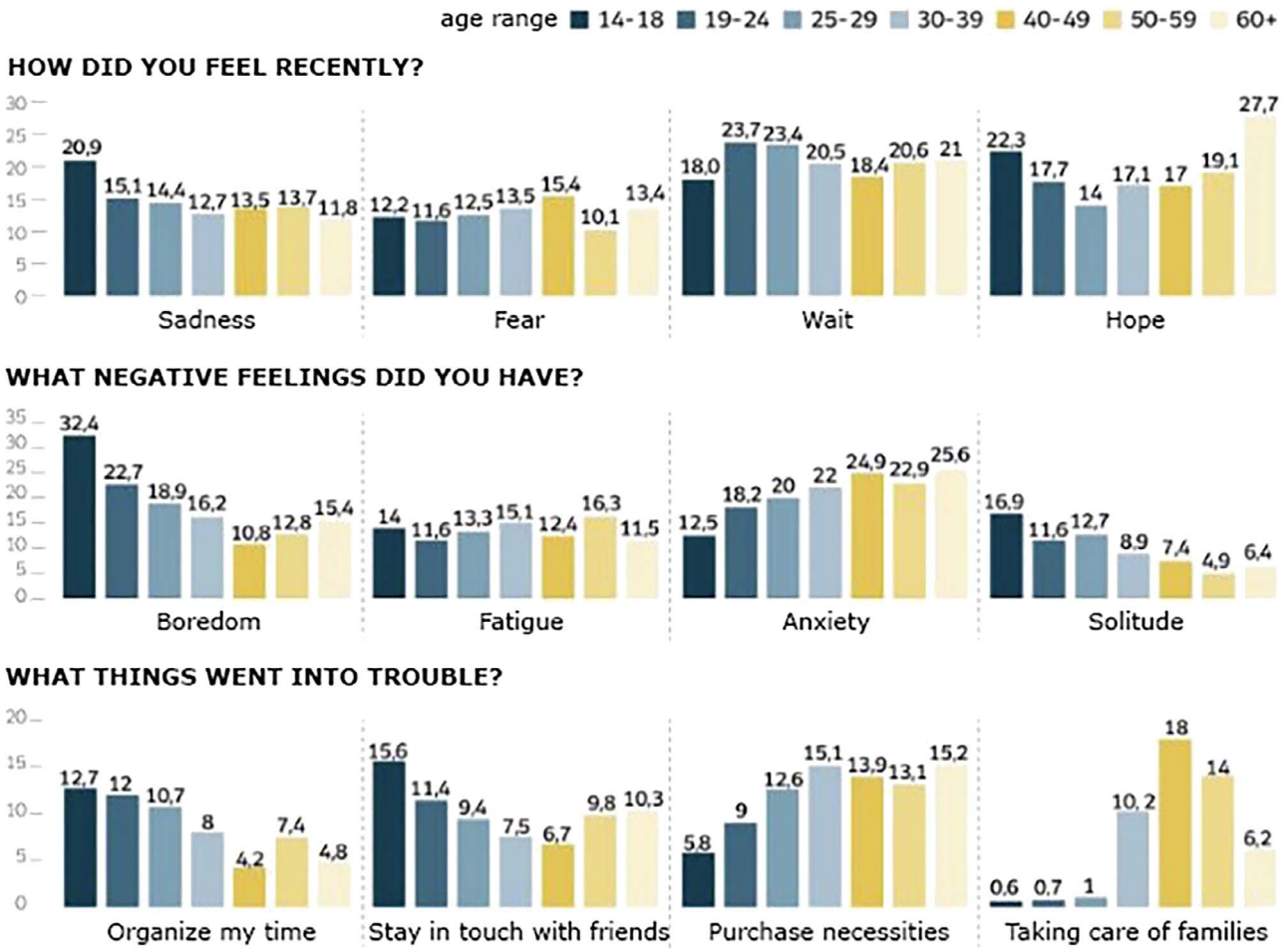

FIGURE 2. Example of a simple static bar chart (content in the chart has been translated from its original language to English). Credit: Newspaper Corriere della Sera, March 24th, 2020 – Milano, Italy.

small team of volunteers. Thus, although there is great potential for automating the analysis of survey responses that investigate people's needs in situations of emergencies, turning preliminary analysis into digestible information ready to be used by designers, still requires human intervention and a considerable amount of manual work.

3.3. Enabling remote, open and decentralized collaboration

Since the beginning of the pandemic, and specifically during the first lockdowns taking place in many countries, digital technologies contributed to remote collaboration in many different fields, as described above. In the DfE project, they facilitated the creation of a completely virtual network of stakeholders, and the design of an open-innovation digital platform. However, this virtual collaboration persisted throughout the 2-year pandemic period, allowing the team to further develop this initiative. The design process of this initiative during this time was extremely flexible and fast-paced, not only because the context needed it, but because the research team had to quickly explore, test and adapt the design process to the technologies available. We argue that our design process was enhanced by the technologies at hand, which will be described in this section. We argue, too, that utilizing technologies in this way to adapt and respond to a rapidly changing context is what made the DfE project innovative and successful.

Digital technologies supported collaboration around DfE in five main areas (Table 1): 1) website design and development; 2) survey design, data collection and organization and visual analytics; 3) dissemination and communication of the project; 4) design and development of the open-source design platform; and 5) project management, task management and team and stakeholder collaboration. Below, we describe the technologies we adopted and how they enabled these areas.

3.3.1. *Website design and development*

Web development technologies were used for two purposes: 1) the creation of the main DfE website for the online presence of the project and 2) the creation of a data platform for sharing our data results.

The DfE website

The DfE website was meant to show an updated description of the project and all the related initiatives, as well as to display their outcomes. It was created to allow interested actors to contact the team, participate in the initiatives and share calls to action. An off-the-shelf website building and hosting platform was chosen. The DfE founding team was looking for a solution that offered a web-based platform that could be used for quick implementation and without the need of high technical skills. Throughout the initiative, this choice allowed the DfE growing team to collaborate remotely on the maintenance and updating of the website, as

TABLE 1. A summary of digital technologies we used in different areas

Website Design and Development	Online Survey and Data analysis	Communication Strategies	Open-source Design Platform	Team Collaboration and Management
Webflow, Squarespace, Google Apps Script, Figma, Firebase, GitHub, Google Sheets	Google Forms, Google Sheets, Python, D3.js, Keyphrase Digger (KD) tools	Facebook, Twitter, Linkedin, Instagram	Google Sheets, Creative Common CC4.0	Zoom, Microsoft Teams, Slack, Asana, Notion, Miro Board, Google Docs

well as to involve team members with no coding experience. More importantly, it allowed the team to rapidly build a first version of the website, which was launched just 1 week after the start of the first lockdown in Italy. The website was essential to give the initiative an identity and to share the online survey, which was accessible from the homepage.

As the project grew, the DfE website underwent two main redesigns, corresponding to two different pivotal moments. First, just a few days after the launch in Italy, the project started to attract different partners from around the world, eventually involving research teams in 12 countries after four months. Each partner was responsible to disseminate the initiatives in their own countries and languages. This required the DfE team to create a modular structure for the website, one that could host the same contents in different languages. The website design and hosting platform provided enough flexibility to implement these changes. Second, new data from the online surveys were received daily. In the first version of the website, the data collected from the survey was displayed through both static and interactive visualizations created asynchronously and published on a dedicated section of the website. Due to the growing frequency of updates, using asynchronous and manual creation of the visualizations became unsustainable for the team. Therefore, the second redesign separated the exploration of the data analysis' outcomes, with the creation of a dedicated data platform as an independent web application. The redesign also focused on bringing a coherent visual design between the data platform and the DfE main website.

The data platform web application

The data platform was created to distribute the outcomes of the survey data analysis online. It was meant as a starting point for participants in the design challenges, a source of information to understand the experiences and problems of the people they were designing for. Additionally, the data platform was intended to expand the impact of the data that we collected; a place where academics and potential partners could harness the information and the knowledge generated by the data analysis for their own projects.

Early on it was decided that the results of the data analysis were to be shared as 2D visualizations. Moreover, as explained in the previous section, the team wanted to create the visualizations dynamically, synchronizing them with the survey results. These objectives led the team to create a web application. Figure 3 summarizes the main elements of the web-application architecture.

Off-the-shelf solutions were selected to allow and facilitate collaboration. Online spreadsheets were connected to the application's main database. In this way, partners could add data and update translations, and the core team could edit any text on the website without the need for coding skills. The platform was created using a website building service, different from the one selected for the DfE website, that allowed users to run custom code and load web libraries.

Collaborative design and development

Digital technologies played a fundamental role in enabling team members around the world to collaborate remotely in the creation of both the DfE website and the data platform web application. During the phase of design, low- and high-fidelity prototypes of the web pages were created with a web graphic editor; team members were able to exchange feedback using the comment feature and could edit the same file. Periodically, the designs and implemented pages were reviewed during online meetings using teleconference software. In these instances, the choice of using online visual editor platforms for web creation meant that all team members could visualize the current state of the website, test the navigation and contribute with incremental improvements (e.g. correcting typos, updating images and adding missing links).

The technical development of the data platform web application also highly benefited from the use of web technologies. They provided distributed version control and source code management for a team that worked in different time zones (Boston, San Francisco, London and Milan), even sometimes on the same parts of the code.

3.3.2. *Online surveys and data analysis*

As part of the initial data collection process, we promoted the completion of online surveys addressing, among other things, how people were feeling and what they were experiencing during the first lockdown. Also, in this case, online surveys were realized by Google Forms and shared through social media. Using online tools for surveys creation and dissemination allowed us to collaborate remotely with partners, who could edit surveys online, for translation in different languages. We surveyed people in 12 different countries—in order of involvement, Italy, USA, Brazil, Spain, France, South Korea, Mexico, Ecuador, UK, Peru, Russia, Austria, gathering people's feelings, concerns, needs and wishes, especially in the first lockdowns, but also later, during the subsequent phases of the pandemic. This context-specific data were then made available through the platform, boosting the generation of ideas addressing problems that emerged in the pandemic.

We used the online survey and digital platforms to showcase and communicate the needs and problems that people were experiencing at that moment in time, allowing designers to choose and work on the issues they wanted to address. Digital technologies and remote collaboration were key for the data analysis and data visualization, making the design process for those who wanted to contribute to the design of solutions faster and easier.

3.3.3. *Communication strategies*

We used social media platforms in two main phases of the process, initially, to share the surveys and invite people to respond. Subsequently, we used them to disseminate the design challenges and promote the participation of designers in addressing and

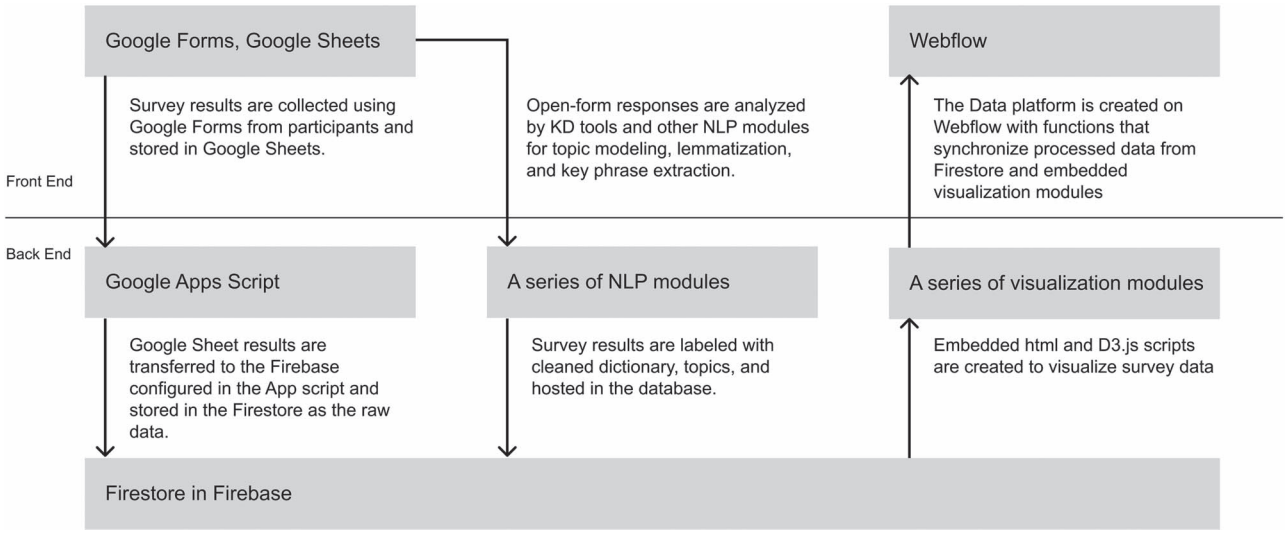

FIGURE 3. Web application architecture used for developing the DfE data platform.

proposing solutions to the problems identified through online surveys. Furthermore, social media platforms promoted the involvement of the general public, stakeholders and partners. In addition to the dissemination on social media platforms, we reached out to designers by partnering with local actors—a university in Italy, a university and a design museum in Brazil to create two ad-hoc design challenges (Colombo and Ciuccarelli, 2020).

3.3.4. *Open-source design platform*

Open-source seed ideas were disseminated through the DfE platform, and the virtual network of stakeholders (universities, professionals, non-profits, companies) was invited to contribute to their development. We aimed to create a platform that allowed for decentralization, where various stakeholders and users could spontaneously contribute to specific projects through the platform, without the need for centralized management. The website included two sections dedicated to fostering the use, implementation and adaptation of ideas. One page described how ideas could be modified and implemented according to the open innovation approach we had adopted. Another one consisted of a form that interested parties could fill in to claim interest in developing ideas published on the platform, in case they wanted to seek the DfE team's support in finding partners or additional expertise. However, this proved to be one of the least successful aspects of the project: only a subset of ideas was developed, and some of them were supported and facilitated by the core team, especially after the emergency phase (see 3.3). The design of the platform did not include features that allowed for direct communication among different stakeholders (e.g. different experts or authors' ideas). This element might have negatively contributed to the implementation phase.

3.3.5. *Team collaboration and task management*

For managing the diverse set of tasks among the many team members that were spread out across the globe, the core team used web apps to keep track of tasks and deadlines, making sure that all pending work was completed on time. These tools also helped improve asynchronous communication by allowing team members from different regions and time zones to leave comments and questions for others, reassign tasks, or ask for help when encountering roadblocks. The team used other online resources to plan work ahead, take notes and organize and synthesize discussions, allowing team members to provide inputs and outputs for others to continue with their own tasks, allowing everyone on the team to perform their work until completion. In addition, and for facilitating faster communication, the team took advantage of certain web and app communication channels. These communication tools helped team members to come to agreements much faster and to work more efficiently.

Furthermore, teams based in different countries collaborated through other online mediums, especially for brainstorming and rapid prototyping. We benefited from the enhancement done on video conference calling apps which allowed us to converge despite the different time zones and locations in a meeting. Online meetings were particularly important to come to agreements and shared understanding, which also boosted remote collaboration by allowing team members to share ideas, thoughts and update each other on the work in progress. Additionally, these meetings were particularly useful when there were doubts or disagreements, making conversations easier. Video conferencing calls were fundamental for connecting and collaborating with external stakeholders as well.

3.3.6. *Reflection*

This section showcases the essential role HCI technology advancements played to promote the design of an open and decentralized online platform and enhance collaboration and networking during the pandemic. During the development of the DfE, the team continuously reflected on its emerging needs, including 1) quickly developing web pages and web applications to serve people in the situation of emergency; 2) facilitating the collaboration across the team, both synchronously both asynchronously; and 3) involving team members with various levels of technical skills in web platforms management. To that end, several existing digital technologies and solutions were used to fulfill the previous needs in the following ways: 1) visual-based web editors allowed creating website pages collaboratively and asynchronously without the need for coding skills; 2) custom code features allowed to expand of the features of website builders to connect them to the web application architecture; and 3) Google API allowed to easily synchronize data sources with the web app's database and provide updated knowledge.

The DfE case study shows how data and algorithms have supported the creation and dissemination of open-source design solutions in a multifaceted, dynamic and challenging context. We argue that computers and the internet have also provided designers with the opportunity to reach broader audiences and have the potential to change the concept of open innovation in design during situations of emergency.

3.4. Inspiring and implementing solutions addressing people's needs during COVID-19

Many of the solutions that were collected on the DfE platform leverage the potential offered by digital technologies. To date, the digital repository includes 59 seed ideas[9] of solutions helping individuals and communities to cope with the pandemic. Seed ideas were clustered into four categories, based on their main goals: physical safety, well-being and mental health, shared experiences and community support. All ideas are published under the Creative Common CC4.0 open license, which makes them available for development by any individual or organization, including for commercial use. Some of them have been developed further by the authors or by third parties, while others have been fully implemented in different areas of the world.

In this section, we analyse the repository to investigate how digital technologies inspired the creation of seed ideas, and how, on the other hand, they might have halted the rapid implementation of many of such solutions.

3.4.1. *Seed ideas categories*

All seed ideas were clustered into four categories, according to their main goals and the types of solutions they include:

- *Physical safety:* these solutions address the need to keep society safe during the pandemic and to limit the spread of the virus. They help people to protect themselves, follow safety regulations and guidelines, stay informed, or perform daily activities safely (e.g. keeping distance).
- *Well-being and Mental Health:* these solutions are primarily focused on making people feel good during the pandemic and reducing mental health issues. They include ideas for keeping a healthy lifestyle, staying connected with others, finding new routines and keeping track of people's own emotions.
- *Shared experiences:* solutions in this category aim to reconnect people either online or offline. They allow for the generation of experiences that are lived and shared with others—family, friends, and also strangers.
- *Community support:* these ideas provide some forms of support to or by local communities. They include, for instance, networking platforms for supporting neighbors or for exchanging favors, or design for temporary vaccination centers.

We used these categories to analyse how computing and digital technologies supported different scopes and inspired solutions to address these different issues.

3.4.2. *The role of digital Technologies in Seed Ideas*

When inviting designers to submit their ideas to the DfE platform, we asked them to fill in a template to describe ideas consistently. The two-page template featured spaces for images and text description of the ideas. Authors had to indicate, in addition to the idea description, what technologies or resources were needed to implement the solution and who could contribute to the idea implementation (expertise and competencies needed, but also stakeholders, organizations, etc.). After analysing all the ideas descriptions, in this section we explore how different technologies were adopted by designers to inspire and enable solutions addressing social issues during the pandemic.

The first analysis regards the types of solutions that were submitted to the DfE platform. As reported in Figure 4, 45 of 59 seed ideas (76.3%) are *digital systems*, i.e. they include digital components, ranging from mobile apps, to digital payment platforms, to chatbots. A small group of ideas (13.6%) include *interactive or smart tangible artifacts*, which usually embed sensors, circuit boards and actuators, and require some forms of tangible interactions. An example is 'Bee Totem', an interactive totem placed in public spaces that explains COVID-19 safety measures to passersby. Another example is 'Amet', a tangible smartphone accessory to send virtual hugs by tactile feedback, designed especially for seniors. In this case, the solution is also connected to a custom mobile app (therefore it mixes digital and tangible components).

While many of the seed ideas create online digital, and virtual spaces for connection or entertainment, a small subset (16.9%) consists of digital platforms or solutions that also include a tech-free (TF) aspect, i.e. they enable or encourage off-line and tech-free activities as part of the experience, for example, writing physical letters to strangers, exchanging gifts in real life, or delivering goods to neighbors. Finally, about a fifth of the solutions (18.6%) are *fully analog*, i.e. they do not include any digital, smart or interactive technology. Examples are 'Higienizador Modular', a wearable hand sanitizer dispenser for children and 'Face Shields Covid-19', a plastic face shield to protect healthcare workers.

Despite most of the solutions being digital, the prominence of digital technologies was different in the four seed ideas categories, suggesting that designers might see certain technologies better fit some scopes or uses (Figure 5). In the *Physical safety* category, the number of analog solutions equals that of digital solutions. This is the category where most analog systems were ideated (8 of 11 in total). None of the seed ideas in this group encourage tech-free activities, but a few consist of interactive artifacts. Examples are 'Angelo', a voice amplifier that enables to talk with elderly people suffering from hearing impairments from a distance, or 'Medimate', an AI agent embedded in a smart mirror for contactless triage and check-up at the hospital.

Interestingly, all solutions supporting *well-being and mental health* are digital. Two of them are paired with interactive physical artifacts, while another one incentivizes offline and tech-free experiences. A deeper analysis reveals that these solutions are aimed at 1) improving people's relationship with technology (especially helping elderly people to interact with digital systems, access the internet, or use social media); 2) entertaining people by giving them access to online contents; or 3) supporting old or new positive lifestyles, habits, or routines, including new ways to connect to fight isolation (e.g. 'routine planner' or 'productivity vs procrastination', which aim respectively to create new routines and overcome procrastination at work). In addition to these scopes, some of these solutions were aimed at more directly supporting mental well-being, for example, by tracking one's emotional states, or by delivering personalized good news. Digital technologies, despite becoming more addictive during lockdown (Eidi and Delam, 2020; Király *et al.*, 2020; Montag and Elhai, 2020; Yue *et al.*, 2021), were seen as the main resource to support physical, mental and emotional well-being in isolation. They could allow people to fill in the void caused by the disruption of any human connection and routine, by providing alternative activities and online contents (recipes, museum visits, music recommendations, courses) and by giving access to web

[9] https://designforemergency.com/ideas-catalogue

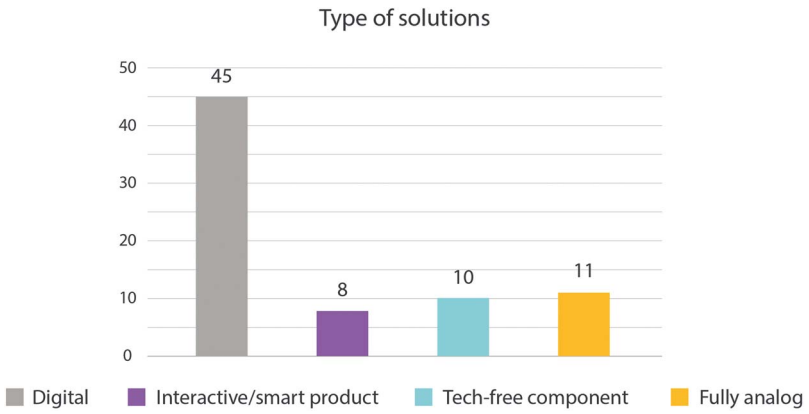

FIGURE 4. Type of solutions based on digital technologies.

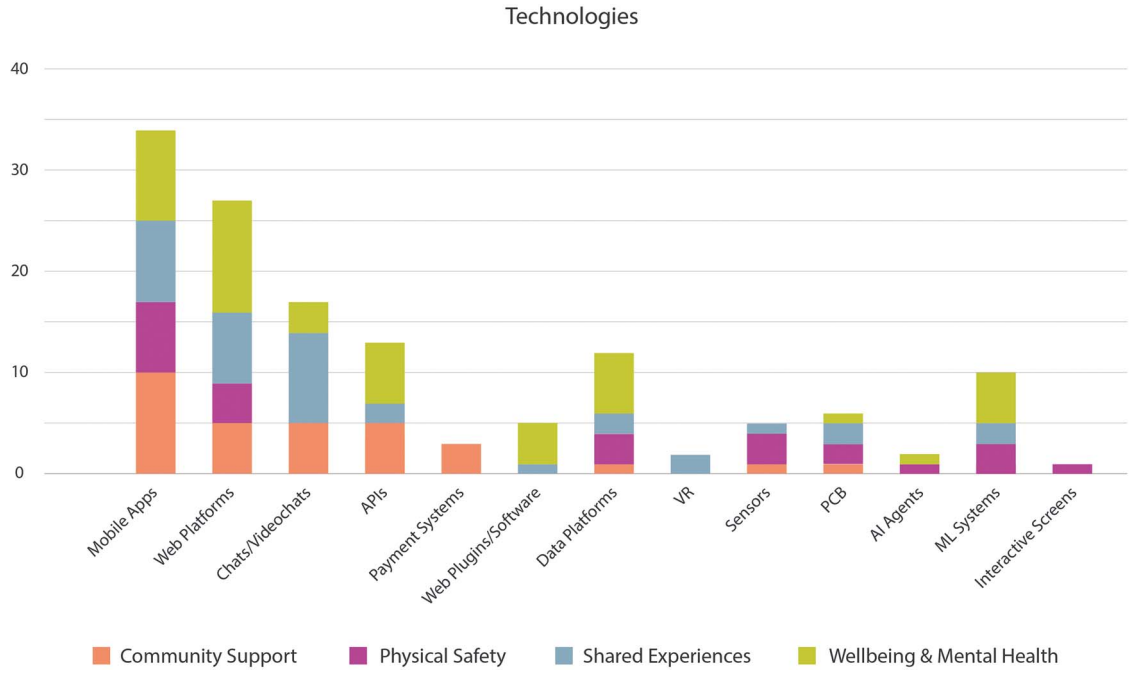

FIGURE 5. Type of solutions per Seed Idea category.

platforms. It is worth noting that the main digital technologies used in this category, in addition to web and mobile applications, are APIs (to exchange data with existing services, e.g. Google maps), software plugins (e.g. to facilitate access to existing online platforms or resources, such as social media), data platforms (e.g. to create repositories of activities, physical exercises, etc.) and ML systems for personal recommendations of activities, online contents, or news (Figure 6).

In the *Shared experiences* and *Community support* categories, most of the solutions are digital, but respectively, half and a third of them also offer tech-free experiences. Looking at the technologies (Figure 6), most of them are based on mobile apps and chat or video chat platforms, which in some cases aim to create networks of people to help each other, or to support marginalized people (from doing favors, to delivering groceries or other goods, to supporting homeless people). Two solutions in the *Shared experiences* category make use of virtual reality to connect people, for instance to attend concerts together, remotely.

In general, more than half of the solutions (57.6%) are based on mobile apps. Web platforms, often mentioned as a possible alternative to mobile apps for certain web-based services, were used in 45.8% of the seed ideas. More advanced technologies were also adopted, such as virtual reality—as mentioned above and AI and ML technologies. AI agents were used in two instances, to keep company to elderly people and to improve physical safety, while ML systems were adopted mainly to generate hyper-personalized experiences for well-being and mental health. In other instances, ML is used to create deep fakes for good (to help people follow safety rules), fake news detection and to enable voice or image recognition.

3.4.3. *Ideas development and implementation*

A subset of seed ideas was fully implemented and made an impact on communities, while others were further developed by either the authors or third parties, but they eventually did not turn into fully working systems. Table 2 shows the seed ideas that were further developed or fully implemented, to the authors' knowledge. It is important to note that more ideas might have been implemented without notifying the DfE team, as they were openly published for inspiration and free reuse.

Interestingly, the three ideas that were fully implemented and that made an impact in the emergency phase are completely

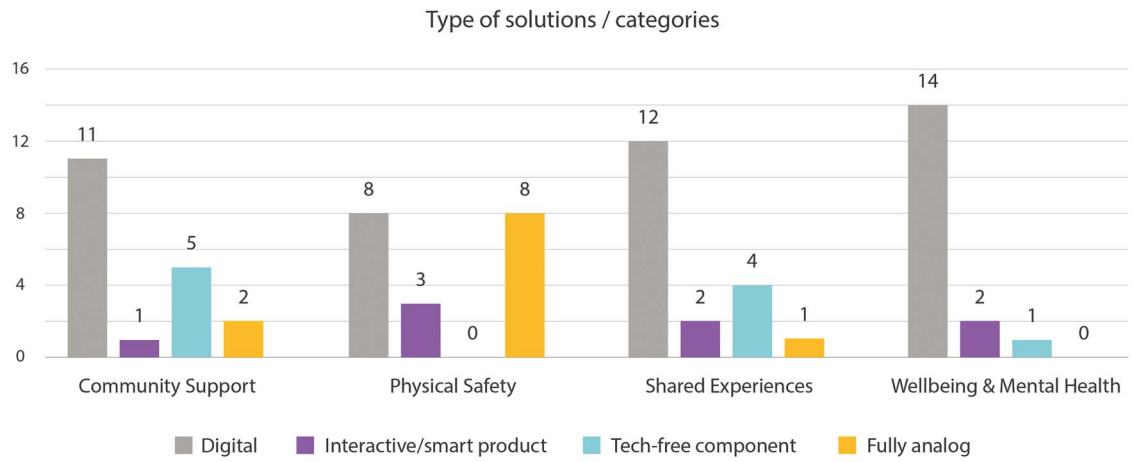

FIGURE 6. The figure shows the types of computing technologies that enable solutions published on the DfE platform, and how they are used in different categories.

TABLE 2. The table describes the seed ideas that were further developed, to the authors' knowledge. It also indicates in what phases of the pandemic and where they were developed, the stakeholders involved and if they were fully implemented, making a social impact

Phase	Seed Idea	Description	Type of solution	Region	Stakeholder	Implementation
Emergency	Face Shield	Face shield for healthcare workers	Analogue	Brazil	Manufacturing facilities, hospitals	Yes
Emergency	Face to Face	Face shield for healthcare workers	Analogue	Brazil	Manufacturing facilities, hospitals	Yes
Emergency	Hand sanitizer	Wearable hand sanitizer dispenser for kids	Analogue	Brazil	Manufacturing facilities, universities, schools	Yes
Emergency	COVID-19 icon set	Ready-to-use vector icon set for COVID-19 information	Digital	Multiple countries	/	Yes
Emergency	Heart to Heart we boost	Web platform to boost micro-interactions	Digital + TF	Multiple countries	/	No
Transition/ New normal	Angelo	Voice amplifier for communication with seniors	Interactive artifact	Italy	Nursing homes, high schools	Yes/ongoing
Transition/ New normal	Hummingbird	Emotion tracker	Digital +Interactive artifact	Multiple countries	Hospitals	Yes/ongoing
Transition/ New normal	Gentle Case	Tablet case to access apps through tangible tokens	Digital +Interactive artifact	Multiple countries	Nursing homes	Unknown
Transition/ New normal	Procrastination vs. Productivity	Web platform to increase productivity	Digital	USA, Italy	/	No

analogue. In addition to those, an idea was shared as already fully implemented, consisting in a set of COVID-19–related vector graphical icons, which could be freely reused. Despite it being digital, this solution did not require any expertise outside the design domain. Other seed ideas were fully implemented or partly developed in subsequent phases of the pandemic, in some cases with the support of the DfE core team or partners. All these ideas include digital systems or interactive artifacts.

3.4.4. *Reflection*

While digital technologies inspired the ideation of solutions addressing different social issues that emerged during the pandemic, they might have also represented one of the main obstacles for their development and implementation. As shown in Table 2, only analogue solutions were fully implemented in the emergency phase, while the digital ones required more time to be developed. The designers involved in the generation of ideas did not seem to have the resources or possibilities to implement them. For all the ideas published on the platform, designers mentioned additional competencies and skills that were required to develop their concepts. They referred both to technical expertise for ideas implementation (e.g. software developers, computer and data scientists, engineers), and to different types of stakeholders, from hospitals to psychologists, to municipalities, as well as business or social media experts who could successfully disseminate solutions. In addition to the lack of technical skills in the design teams, the implementation gap might be due to designers' lack of entrepreneurial expertise (Aakko and Niinimäki, 2018; Gaglione and İdil Gaziulusoy, 2019). Because the audience of the DfE platform consisted primarily of designers, it is possible that the effort required to build such solutions exceeded the available resources in terms of time, effort and competences, as well as it

was seen as a contribution that designers are not supposed to provide.

4. DISCUSSION

In this section, we discuss the advantages digital technologies can provide in responding to emergency situations, based on what we experienced in the DfE initiative. We outline elements that emerged as critical and that can be improved by properly designing future meta-design collaborative initiatives for ideas generation, dissemination and implementation. Moreover, we address how HCI and advanced digital technologies, such as algorithms and AI, might contribute to the rapid implementation of seed ideas in similar initiatives, to accelerate impact and promptly respond to emergency situations with a human-centered approach.

4.1. Digital technologies enable remote and prompt intervention

DfE was characterized by two aspects, which were both enabled by computing and digital technologies: *remote volunteering* and *prompt intervention*. Spontaneous, informal and short-term volunteering is a common phenomenon during emergencies and crises (Whittaker *et al.*, 2015; Aguirre *et al.*, 2017; Simsa *et al.*, 2019). In the past, volunteering during an emergency meant physically moving to the places where such emergencies occurred. In recent years, online volunteering started to emerge, to contribute to activities that were collateral to on-site volunteering (H. K. Liu *et al.*, 2017). During COVID-19, digital technologies became indispensable not only to coordinate responses of volunteers (Trautwein *et al.*, 2020) but also to generate a new type of social support—one happening fully remotely. Remote, online volunteering was essential in the pandemic, as COVID-19 forced people in isolation, therefore spontaneously moving to even local hotspots to provide help was highly discouraged, or even forbidden.

In our initiative, digital technologies provided people with an opportunity to volunteer remotely, by 1) sharing information on the issues they were experiencing (survey participants); 2) providing open ideas for solutions to support people during the emergency (designers); and 3) collaborating on a global level to spread the initiative and implement ideas in different local contexts (researchers, partners). The response, especially at the beginning of the pandemic, was high, with people feeling compelled to contribute. DfE embodied a new paradigm for volunteer interventions, in which people can contribute with data, ideas and various skills, from any place in the world, to the development of solutions addressing specific needs that emerge locally.

Moreover, DfE was enabled by the evolution of digital technologies that made it possible to promptly intervene in a short time. For instance, they allowed us to quickly build a website (through modular and code-free platforms, which could be adapted to fast-changing conditions and partnerships), generate and disseminate digital surveys (through digital forms and social media) and perform preliminary quantitative analysis of the collected data. These activities were initially accomplished in the span of 1 week, by only two people. Without the existence of such digital tools, DfE could not have been imagined or implemented with the same speed and effectiveness.

A deeper and more structured analysis of the possibilities provided by technology can pave the way to the generation of future services and solutions that allow for rapid and remote interventions in situations of emergencies, both to understand people's needs and to quickly implement solutions addressing them. Starting from the lessons learned through the DfE initiative, new, more structured meta-design approaches and processes leveraging the potential of digital technologies may be developed to quickly address emergencies through remote collaborative design.

4.2. Digital technologies support open ideas

DfE provides new routes for the global dissemination of ideas by a virtual open platform. The new paradigm for remote and design-oriented volunteering was made possible and reinforced by another emerging paradigm proper of the digital world, that of *open source*. Thanks to the adoption of an open-source CC license, ideas could be published and freely reused, and authors still received credits. This aspect might be especially appreciated by professionals operating in certain design domains, where open sharing and reuse of ideas is not customary. For instance, in product or interaction design, protecting and patenting ideas is common practice. DfE was an attempt to extend the open-source and open innovation paradigms to areas of design that are not used to operate in it. This aspect should be further investigated, to assess if and how the choice of making ideas open source in a context of emergency might affect designers' decisions to contribute to similar initiatives.

4.3. Accelerating impact through advanced digital technologies

Although DfE was initially conceived with the goal to immediately respond to an emergency by designing and realizing solutions addressing new needs, it had to adapt to changing conditions which eventually hindered the rapid implementation of ideas. At least four elements have contributed to slowing down ideas' implementation in the emergency phase. First, the unexpected expansion of the initiative in multiple countries required significant coordination efforts for data collection, analysis and visualization in different languages, which brought the core team to shift the focus from ideas realization to data management. Second, the unpredictability of the pandemic evolution affected the motivation and engagement of partners and stakeholders over time; for instance, once the first lockdowns were lifted, people felt that the emergency phase was over, therefore local implementation of ideas was perceived as less compelling and motivation dropped. Third, the platform did not offer an immediate way to build networks of professionals or organizations that could collaborate in ideas development. Fourth, significant effort and proactivity were required to implement ideas that were mostly digital and needed advanced programming skills and resources to be developed. We believe that, once again, digital technologies offer opportunities to increase the impact of similar initiatives in the future, by overcoming some of these challenges.

4.3.1. *Increasing motivation and engagement*

One of the difficulties we faced was keeping partners engaged and involved for a long period and enabling them to remain proactive and take responsibility for certain parts of the initiative. As the first lockdown was lifted, there was increasing optimism towards a fast return to normal, and people tried to go back to their routines. Therefore, less time was available to work on pandemic-related initiatives, which seemed not urgent anymore at that moment. On average, partners' involvement sensibly faded with the first lockdown lifting and increased again with the second or third lockdown. Of course, it is not possible to overlook the complexity of this particular type of emergency, and the fact that all team members, stakeholders and partners, were at the same time suffering from the pandemic, and trying to contribute by

dedicating time, skills and resources to this initiative. However, it is important to consider how common human reactions to emergencies can affect volunteers' engagement in design initiatives. For example, the need to overcome the emergency stage, go back to normal and ignore future risks in an attempt to reduce anxiety and 'preserve ontological security' (Monteil *et al.*, 2020) might play a role in volunteer's involvement over time. We witnessed an impressive wave of enthusiasm and willingness to contribute to DfE in the first few weeks of the pandemic, which gradually faded. Advanced digital technologies might be employed to both monitor and predict changes in people's, volunteers' and partners' engagement to similar initiatives. Moreover, digital technologies may help to keep the engagement high (Tan *et al.*, 2022). For instance, AI could provide personalized strategies to keep people engaged over time (Gao *et al.*, 2022) by analysing motivations for volunteering (Kulik *et al.*, 2016) and personal characteristics.

4.3.2. *Improving collaboration*

The DfE web platform did not directly support the creation of collaboration teams for ideas implementation. The platform provided the designers' contacts, but not the possibility to quickly and directly get in touch with them. This might have slowed down or hindered the creation of a network of designers, makers and other stakeholders interested in open ideas implementation.

Some features could be implemented in these types of platforms to foster collaboration and exchange of open ideas and expertise. For instance, digital technologies might facilitate the connection of different stakeholders and competence providers, together with companies that might be willing to invest in certain solutions. Automating certain tasks such as finding common interests, recommending contents, connecting people and inviting them to collaborate might be extremely helpful. In DfE, building partnerships by connecting stakeholders was effortful, as it requires identifying common interests, connecting public or private entities and coordinating partners, who should align goals and agree on cooperating on a certain solution. This happened with some of the ideas that were implemented in later phases of the pandemic, but it took time. Supporting these activities through digital technologies, including AI algorithms commonly adopted in other social platforms, might improve the rapid implementation of ideas, to make an impact in the first phases of an emergency.

4.3.3. *Accelerating impact through automation*

Recent advancements in digital technologies have the potential to accelerate the implementation of digital systems and services, for instance mobile apps. Both research and commercial solutions are being developed in this area. One example is the MIT platform *App Inventor*[10] (Pokress and Veiga, 2013), a cloud-based visual programming environment that allows anyone to build functional apps much faster than with traditional programming environments. Other commercial tools are being developed to rapidly implement mobile interfaces through a low-code approach. For instance, *OutSystems* (Henriques *et al.*, 2018) is a user-centered development platform for enterprise apps, which generates high-quality apps through a modular approach.

Using modular building blocks to develop basic mobile apps would make it easier to implement many of the ideas published on the DfE platform. In future iterations, these types of resources could be connected to the DfE platform to invite designers, as well as users, companies and organizations to develop ideas in a more effortless way.

4.4. Digital technologies and inclusivity

Some of the ideas collected through the DfE platform targeted and mitigated the lack of inclusiveness and equality due to digital illiteracy or technology inaccessibility, which challenged certain population groups in the COVID-19 emergency (Lai and Widmar, 2021). Moreover, some solutions addressed the needs of homeless, elderly people, or people suffering from mental disabilities, which were even more affected by the pandemic (D'cruz and Banerjee, 2020; Dubey *et al.*, 2020; Kim *et al.*, 2022).

Interestingly, those ideas were designed despite the lack of any explicit reference to the needs of these specific groups in the data we collected and published. Such a gap in our data can be explained by the fact that the digital nature of the DfE initiative carries an intrinsic risk of marginalization and exclusion, which needs to be deliberately addressed in future iterations of this platform, or in similar initiatives. Responding to online surveys disseminated by social media requires to be social media users and to have a sufficient level of digital literacy. Any person who does not meet these criteria is deprived of the chance to make their voice heard and to enable the design of solutions they could benefit from.

We believe this is a crucial point to explore, to develop new approaches to use digital technologies for the design of equitable and inclusive solutions that address the needs of especially vulnerable groups in emergency situations. Previous work in relevant fields can be leveraged, to increase access of different groups of people to digital technologies and initiatives (Le Dantec and Edwards, 2008; Le Dantec *et al.*, 2010, 2011).

4.5. Limitations and future implications

In this work, the DfE initiative is used as a case study to showcase the impact of digital technologies in designing solutions to address situations of emergency. We have laid out the many areas that were positively impacted by technology in the midst of the COVID-19 pandemic and that led to the success of this project. However, this paper intends to reflect on the DfE project by sharing some limitations and future implications.

One of the limitations of this work is that the results of this project are not generalizable, but rather, the issues that emerged should be further analysed. Furthermore, due to the unicity of the COVID-19 emergency and the DfE platform, we lacked any precedent, systematic approach or framework to analyse the platform and provide validated insights or recommendations for the design of solutions applicable to other contexts or other types of emergencies.

This project was built around internet connectivity, and therefore, we acknowledge its limits and the lack of accessibility for a broader audience. We mainly reached out to and surveyed people with access to the internet, leaving others out of the scope of this project. We wish to further develop the initiative's scope and accessibility for future situations of emergency to better serve larger communities, despite the lack of internet access.

Moreover, our data collection was mainly done through surveys. We are aware of the limitations of surveys, for example, compared to other research methods like interviews, which may have shed light on deeper needs and desires. However, surveys presented a rapid method to reach more people at once and gather data from different regions. Thus, future research is needed to understand participants in more meaningful ways, and perhaps to come up with ideas and tailored design methods of inquiry that

[10] https://appinventor.mit.edu/about-us

might be applicable to rapidly gather information and insights from people's needs in situations of emergency. We hope that a deeper analysis of this platform can inspire the development of those potential methods.

We acknowledge that the scale of this initiative might have greatly affected the applications of digital technologies and the implications and results discussed in this article. The outcomes might be quite different, had the initiative involved a larger or smaller number of countries and a more diversified audience.

Finally, this initiative grew with and adapted to the unpredictable and changing context of a global pandemic. When we launched DfE, we could not imagine that the COVID-19 emergency scale and duration would be of this magnitude. The original idea of DfE underwent many transformations, to accommodate the continuously changing reality of the pandemic, but it was still able to maintain its original scope. However, some of the choices we made were heavily affected by the available resources and information, and were not forward-looking. For example, if we knew in advance that researchers from many countries would have joined the initiative, we could have planned the data analysis differently and more efficiently. Therefore, some of the issues we discuss in this article might be overcome by careful planning. We hope to lay the basis for that in the future.

5. CONCLUSION

The DfE initiative serves as an example of the importance of HCI and digital technologies in designing solutions in situations of emergency. In this article, we discuss how digital technologies allowed us to develop the DfE initiative following both a meta-design and an open innovation approach, despite—and because of—the complexity and uncertainty of the pandemic scenario; this prevented us from planning in advance virtually any move, enabled participated evolution creating also a sense of community. This work sheds light on ways in which similar platforms can be developed in the future, to address people in situations of emergency in different contexts. By sharing insights on how technologies supported the creation of the DfE initiative, we hope to inspire the design of new open and collaborative initiatives that do not need to be created spontaneously and during an emergency, but that can be carefully planned to be both flexible and effective, when emergencies hit.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials.

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