Promotion of Community Resilience through Citizen Science Approaches

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The promotion of community resilience is a complex and understudied phenomenon. This article aims to contribute to this literature gap by assessing the role of citizen science (CS) approaches in the development of community resilience, since CS is considered a promising approach for generating new knowledge through fostering the participation of citizens (non-professional scientists) in research activities. The results show that CS approaches are relevant for developing resilience abilities through i) the collection

Introduction

In recent decades, the occurrence of natural and technological disasters, with devastating impacts on local communities, has become increasingly frequent around the world (CRED, 2022). In 2021, the Emergency Events Database (EM-DAT) recorded 432 natural hazard-related events worldwide, which affected more than 101.8 million people, causing 10,492 deaths and $252.1 billion in economic losses. For this reason, 2021 is the fourth most damaging year recorded in EM-DAT over the last two decades (CRED, 2022). Given the current trends in population growth and urbanization, as well as climate change, it is expected that more and more people worldwide to be exposed to various types of hazards, such as earthquakes, storms, and epidemics. As a result, there is the urgency to make disaster risk reduction and the promotion of resilience a core element in public policy, especially in the case of developing countries (Data Pop Alliance, 2015). According to Haja, Teo, Goonetilleke, and Ziyath (2021) resilience is the *of new data from new sources or remote places where data is scarce, allowing for a better characterization of potential hazards, and the identification of community needs, perceptions and behaviours; ii) enhancing community awareness and knowledge about hazard protection; iii) increase human and social capital through specific training initiatives; and iv) promote the cooperation between community (citizens), academia (professional scientists) and government (policymakers), which is relevant for the development of public policies shaped to local context, and aligned with community's needs and expectations.*

ability of social entities to effectively mitigate disaster impacts and to recover in a way that would minimize future social, economic, technological or environmental disasters.

The relevance of human agency in the promotion of community resilience is highlighted in several studies (Bristow & Healy, 2014). Nevertheless, this is easier said than done, since there is still a limited knowledge about how to effectively promote the active participation of communities in the development of local resilience, and how individual and community recovery can be effectively supported (Talbot et al., 2020). In this case, citizen science (CS) has been highlighted as a form of research collaboration that involves citizens in research activities together with professional scientists, and, thus, promoting the development of skills and social networks, as well as the generation of data on local communities (Chari et al., 2019).

This chapter provides a critical review of the available literature on the role of CS approaches in community resilience, and, therefore, contributing to a better understanding of how CS can foster community resilience. The present chapter hopes to provide several contributions to both theory and practice. On the one hand, it attempts to explore the broader effects of CS initiatives on communities. Typically, the outcomes of CS include research findings and publications, which contribute to scientific advances; legislation and policy measures; and an increase in citizens' skills and knowledge (Gray et al., 2017). However, CS approaches can have broader impacts, such as contributing to the development of a community and making it better prepared to face future challenges. On the other hand, this work seeks to determine if community resilience can be improved through the participation of citizens in CS initiatives. In the literature, several studies have identified the various dimensions that form the resilience of a community, but until now, no study has discussed in detail which measures and initiatives can effectively improve these dimensions. Therefore, the present study hopes to clarify how CS can contribute to each dimension and sub-dimension of a community's resilience and, thus, advance research in this area.

Community resilience: a context-based ability of territories

Resilience is a concept with roots in the fields of environmental change (Bronfenbrenner, 1979; Holling, 1973) and psychology of personal development and mental health (Luthar, 2006). Nevertheless, in the last decade, the term social (or community) resilience has emerged in the field of business and management, mostly due to the general agreement that social systems and ecosystems should be considered together, as they are interdependent and co-evolutionary (Buikstra et al., 2010; Folke, 2006). This is evident, for instance, in the study of Rindrasih (2019), which assessed the impact of the 2004 Indian Ocean tsunami and concluded that it impacted not only the local environment, politics, and society, but also the performance of tourism as an economic sector in Aceh, Indonesia. In this case, the disaster triggered the rise of new forms of tourism that impacted local development.

According to Saja et al., p. (2021, p. 1), "social resilience is defined as the ability of social entities to effectively mitigate disaster impacts and to recover better and to minimize future social disruptions and disaster risks". However, over the last few years, the definition of social resilience has gone beyond the capacity of social entities to "bounce back" from social disruptions, focusing, more and more, on human agency (Bristow & Healy, 2014; Steiner et al., 2018). In this case, the main assumption is that a community comprising individuals who are personally resilient in the face of disasters or crises is likely to be a resilient community (Berkes & Ross, 2013). In the same vein, Buikstra et al. (2010) argued that community and individual resilience are interrelated, since the same factors generally contribute to both levels, even if to different extents. In fact, several researchers have highlighted that community resilience is not only achieved by improving the built environment or by developing or enhancing warning systems and increasing rules and regulations, but also when communities are able to develop a "learn to learn" mentality and the skills and capacity needed to promote innovative solutions in the face of new challenges (Azizi et al., 2022). Thus, a resilient community is "one that takes intentional action to enhance the personal and collective capacity of its citizens and institutions to respond to and influence the course of social and economic change" (Colussi, 2000, p. 5). As a result, a community becomes able to absorb a disturbance (e.g., a crisis or disaster) and maintain its development path or radically restructure system conditions in a way that sets it off from its historical development

Resilience abilities	Plan/Prepare	Absorb	Recover	Adapt
Timeline	Pre-disaster	During disaster	Post-disaster (short-term)	Post-disaster (long-term)
Aim	Prepare the system against identified threats	Absorb the consequences of a shock without breaking and maintaining a certain degree of function	Recover system's functionality at post-shock level	Improve system's capacity to absorb and recover from shocks based upon past experience
Activities	Identification of threats and development of warning systems and mitigating measure	Use of assets to mitigate system losses	Implementation of resources to bring the system back to full function	Promotion of built-in system "learning" through the enablement of the system to change and better cope with system shocks

Resilience abilities. Adapted from National Research Council (2012).
Tab. 1

trajectory (Folke et al., 2010; Martin, 2012). Resilience emerges both from top-down strategies at the state level and from bottom-up approaches at the local community level, which allow communities to plan and prepare for, absorb, and recover from disasters, adapting to new and diverse conditions (National Research Council, 2012). Table 1 presents a social system's abilities to achieve resilience.

Citizen Science: types and characteristics

Some researchers consider CS a specific field of research (Jordan et al., 2015) while others consider it a new form of science (Irwin, 1995) or a new means of research (Shirk & Bonney, 2019). Either way, it has disrupted the way science is conducted, since it enables the generation of new knowledge by fostering the participation of citizens (non-professional scientists) in research activities (Hecker et al., 2018), often in collaboration with or under the direction of professional scientists. It has been widely used in research in the fields of ecology, environmental science, geography, and biodiversity conservation (Kullenberg & Kasperowski, 2016).

In recent years, the number of CS projects has grown rapidly, mainly due to advances in mobile computing, the emergence of devices equipped with sensors, and online sharing technologies (Buytaert et al., 2014) that facilitate the collection of large volumes of data by non-professional scientists, as well as a dynamic interaction between them and professional scientists for hypothesis formulation, research design, data analysis, and knowledge generation.

CS projects vary in terms of focus and structure, as well as the level of citizen engagement. The first level, named *crowdsourcing or volunteered geographic information* (VGI), considers the minimum involvement of citizens. Crowdsourced data include messages, photos, videos, and social media posts produced by citizens, as well as data from mobile sensors, such as GPS and credit cards, among others. In this case, citizens act as a "kind of sensor", enabling a rapid generation of spatiotemporal data with minimum direct engagement. This approach is considered a rich source of continuous of updated information, which helps to improve the quality of analysis (de Albuquerque et al., 2015), and its usefulness in disaster management has already been demonstrated (Goodchild, 2007; Le Coz et al., 2016). However, the use of location-based social network data is not without challenges and there are some arguments over the validity of this source of information (Martí et al., 2019) and the quality of the raw data, which may be low.

The second level is called *distributed intelligence* and, in this case, citizens are required to carry out tasks using interpretation and reasoning, such as sightings (e.g., eBird), transcription of data (e.g., Transkribus), and classification of phenomena (e.g., Galaxy Zoo). Citizen scientists are usually trained before the research work begins. Also, citizen scientists can contribute to the development of a comprehensive scale model of the social milieu, through social cartography or social mapping approaches, in a way that can be studied (Liebman & Paulston, 1994). Several researchers have followed this approach to identify the vulnerabilities of communities through a reflective and open dialogue with community members and, in this way, articulate scientific and popular knowledge (Arias et al., 2016; Khair et al., 2020).

At the third level, called *participatory science*, citizen scientists not only collect data but also participate in the design of the research project through the definition of the research question and the design of the data collection methodology. Moreover, citizens can be involved in the analysis of the data and the interpretation of the results, but this research stage requires the contribution of experts (Haklay, 2013).

The final level of citizen engagement - *extreme citizen science* - is reached when citizens are stakeholders and active participants in all decision-making processes of a scientific investigation (Irwin, 1995), contributing to data collection and data processing and following rigorous scientific principles. In this case, scientific research questions are of interest to both scientists and citizens, and, therefore,

Inclusion criteria	Scopus	Web of Science
Keywords	• Resilient/Resilience • Citizen Science • Crowd Science	• Resilient/Resilience • Citizen Science • Crowd Science
Subject Area	• Social Sciences • Business, Management and Accounting • Economics, Econometrics and Finance	• Social Sciences Interdisciplinary • Economics • Management
Document Type	• Article • Review	• Article • Review Article
Language	• English • Portuguese	• English • Portuguese
Scopus Full Query Search		
TITLE-ABS-KEY ((resilien* AND ("citizen science" OR "crowd science"))) AND (LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "BUSI") OR LIMIT-TO (SUBJAREA , "ECON")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (LANGUAGE , "English") OR LIMIT-TO (LANGUAGE , "Portuguese"))		

Inclusion criteria used for article selection.
Source: Author's own elaboration
Tab. 2

the project outputs should be of benefit to both parties as well. Building on this perspective, *Community Science* has been increasingly recognized as an approach that overlaps with, but also extends beyond, *extreme citizen science* by emphasizing collective action, locally grounded knowledge, and sustained partnerships between researchers and communities. This perspective highlights the importance of co-designing research questions, methodologies, and outcomes with citizens, thus fostering resilience not only through data collection but also through empowerment and community capacity-building. Integrating insights from Community Science provides a stronger conceptual and methodological framing for participatory approaches in risk governance (Pandya, 2012)

Research Methodology

A systematic review of existing literature was performed since the proposed research topic is still understudied and existing literature is spread through several research areas. For data sourcing, we used two scientific databases, Scopus and Web of Science, as both are widely used by scholars and researchers. Moreover, both databases provide extensive and significant bibliographic data sets, comprehensive journal coverage, ease of keyword searching, accessibility within academia, and popularity across multiple disciplines (de Souza et al., 2019). The electronic database search for this review was conducted in December 2022.

To identify relevant articles, keywords such as resilience, resilient, citizen science, crowd science were used. Thus, the search query (resilien* AND ("citizen science" OR "crowd science")) was applied to the 'title, abstract and keywords' field. The process of selecting articles for the research was based on several steps according to the PRISMA method (Moher et al., 2015). The first includes the definition of the inclusion criteria regarding subject area, document type and language (Table 2). No time limitation was considered so that all relevant articles could be identified.

The keyword search retrieved 377 articles from the selected electronic databases, and applying the selected inclusion criteria the number was reduced to 35 articles. A first screening step was performed to remove duplicates, and after excluding 2 identified duplicates, 33 studies were selected for assessment based on their abstracts and keywords. All irrelevant articles were excluded, leaving a total of 22 articles to be read in full, and unfortunately 1 article could not be retrieved. A total of 9 articles were excluded after reading the full text because they did not provide clear information on the impact of CS methodologies on resilience, leaving a final set of 12 eligible articles for analysis.

After applying the inclusion criteria and identifying the final set of eligible articles, it was conducted a qualitative content analysis to assess how citizen science projects addressed different aspects of resilience. Each article was examined in detail and classified according to: (i) the level of citizen engagement (contributory, collaborative, or extreme citizen science), (ii) the resilience ability addressed (plan/prepare, absorb, recover, or adapt), and (iii) the observed or reported impacts on specific resilience dimensions and sub-dimensions. The classification followed a two-step process: first, an independent coding of the articles was performed based on their descriptions of citizen participation and outcomes; second, the codes were systematically compared and synthesized to ensure consistency. This approach allowed for a structured evaluation of the strengths, limitations, and effectiveness of citizen science initiatives in contributing to resilience.

Results and discussion

The sample articles describe CS initiatives in different geographic locations, such as Nepal, Puerto Rico, Brazil, Italy, USA, Australia, among others, and focus on natural environmental hazards such as floods, extreme heat, or volcanic events (Table 3).

The level of citizens' involvement varies from crowdsourcing to participatory science approaches. It was observed that *distributed intelligence*, where citizens perform simple interpretation activities and data gathering, and *participatory Science*, where citizens participate in the problem definition, data collection, and data analysis (with support from experts), were the most used types of CS participation in the different case studies analysed. The absence of Extreme Citizen Science cases in the final sample should not be understood solely because of citizens' lack of skills to engage in complex data analysis and interpretation. Rather, it may also reflect limitations in how research processes are designed, as well as the willingness or capacity of researchers to foster inclusive practices that value and integrate community knowledge. This observation highlights the need for further exploration of frameworks such as Extreme Citizen Science, Community Science, and community-based participatory research, which emphasize more equitable forms of collaboration between citizens and researchers (Hoffman, 2016). In this sense, the predominance of contributory and distributed intelligence approaches in the literature suggests a tendency to use citizen science primarily for data collection and monitoring, while more collaborative or extreme forms remain underexplored. This imbalance reveals a potential limitation in the transformative capacity of citizen science, as less engaged approaches may contribute valuable data but often fail to fully empower communities or integrate their knowledge into decision-making processes.

In the case of resilient abilities, three of the articles report effects of CS on the **ability to plan and prepare for hazards**, mainly those related to environment (e.g., droughts, flooding, invasive species). In this case, CS initiatives were used for collecting information and data, especially using *distributed Intelligence* approaches, which enabled a better understanding of local resources, capacities and vulnerabilities. This was relevant for the development of early warning systems and hazard prevention plans. For instance, in Nepal, floods and landslides are the most devastating natural hazards, and its severity has increased in recent years (Pandeya et al., 2021). Himalayan region is known for its remote and largely unexplored terrain, which has become a bottleneck for improving local flood capacity. In order to enhance local flood resilience, a CS project was implemented for developing accurate flood predictions, through a participatory science approach and the use of low-cost sensing technology (Pandeya et al., 2021). This has enabled researchers to gather data on local resources, capacities and vulnerabilities from remote areas and, thus, overcoming the data limitation in a data-scarce region, fostering the development of an effective community-based flood early-warning system. Additionally, this project was relevant to empower and educate local stakeholders to build flood resilience. When compared with contributory initiatives, such participatory projects show greater potential to strengthen resilience in the long term, since they not only generate data but also foster community learning and local ownership of risk management strategies.

The **ability to absorb the consequences of a shock** was also highlighted in two articles. In the face of major hazard events, resilience depends first on the actions of people operating at the individual and neighbourhood level (Renschler et al., 2010). Therefore, CS is important to understanding people's behaviour and attitudes for assessing the social impact of hazards. Nevertheless, observational data during a disaster in often lacking. CS approaches can overcome this knowledge gap, since it can be used to collect data on people's perceptions, behaviours and attitudes during a disaster. For instance, Zhao et al. (2021) used CS approaches to better understand heat risk in the Phoenix area, where summer temperatures can exceed 49°C. In this case, volunteers were recruited to collect data on location/time, climate, human activities and heat exposure during their daily routine, through paper-based survey and portable sensing, as well as a smartphone app (ActivityLog). The research results allowed to understand user behaviours for daily log activities and how human activities interact with the urban thermal environment, informing further planning policy development. In addition, CS approaches were useful to identify what actions people took to mitigate hazards, as well as how these mitigation measures impacted local well-being. Here, a clear distinction emerges: while contributory approaches are effective in quickly collecting behavioural data during crises, more engaged forms could provide deeper insights by involving communities in co-designing mitigation strategies, which is still rarely documented in the reviewed studies.

In turn, four articles focus on the **post-shock level**, namely how the system recovers its functionality after a major hazard or disaster. CS projects were relevant to understand community's coping capacity and mitigation strategies to overcome the main consequences of hazards by implementing distributed intelligence approaches. These was important for assessing community's preparedness and their ability to apply measures for protecting and reducing hazards impact. For instance, the area around the active Tungurahua volcano in the Ecuadorian Andes (Ecuador) is in persistent danger that could culminate in a major disruptive event. Stone et al. (2014) describe a network of volunteers, known as *vigías*, which started as a compromise following citizens' decisions to forcibly return to risk areas after a forced evacuation. This movement allowed the population to become involved in volcanic monitoring in the area around the volcano, through the collection of scientific data. As the authors note, this civic initiative has played an important role in community response to episodes of volcanic activity, providing a communication channel for community awareness and preparedness, strengthening social capital, mutual relationships and trust among citizens, scientists, and local authorities. As a result, this initiative has brought solutions to the situation created by the reoccupation of risk areas, increasing the community's capacity to take protective measures, as demonstrated by self-evacuations, thus allowing risk reduction. This example illustrates that citizen science initiatives situated between contributory and collaborative models may already produce tangible recovery benefits; however, their scalability and sustainability remain underexplored in the literature, limiting broader generalizations.

Finally, three articles describe how CS could be used to **improve a system's capacity to adapt after a shock**. The capacity to adapt is related with building resilience to cope with future hazards and other stressful events through empowering citizens to design and implement preventive measures by their own. Therefore, participatory science approaches were relevant to develop human and social capital, as well as to design prevention strategies based on the knowledge and experience of past hazard events. J. S. Hoffman (2020) describes a small-scale community-based citizen science initiative to assess the urban heat island effect in the city of Richmond (USA), where community volunteers collected data to provide a description of the climatologically coolest, hottest, and early evening temperatures along pre-determined driving routes that pass through the greatest variation in land use/land cover across the urban area. The data collected allowed the development of a heat vulnerability index map that can identify areas that may need to be prioritised for action due to excessive vulnerability. Thus, this CS project was relevant to improve citizens' literacy, as well as the development of specific emergency and recovering measures to build resilience to extreme heat by using the urban heat vulnerability index as a guide to design the urban space in one of Richmond's hottest and most vulnerable neighbourhoods. Compared to projects focusing only on short-term data collection, this adaptive dimension shows how citizen science can also act as a driver of structural change, encouraging long-term resilience planning. Nevertheless, such transformative projects remain scarce in the literature, highlighting an opportunity for future research.

In most of the cases analysed, the use of data generated from remote sensing is a common practice. Big data (e.g. call detail records, satellite imagery or social media) has shown real and potential value as an important mean to monitor and detect hazards, mitigate their effects, and assist in relief efforts (Data Pop Alliance, 2015). Nevertheless, most of the big data applications for resilience development consist of small pilots (Data Pop Alliance, 2015), which cannot capture specific aspects of vulnerability. In the articles analysed, CS enables to overcome this limitation by combin-

Resilience Abilities	Objectives of CS projects	Output of CS projects	References
Plan/Prepare	Collect data, especially from data-scarce regions, regarding exposure and vulnerability of a community to hazards;	• Development of early-warning systems and tools to support decision making processes; • Shape local-level strategies planning and implementation regarding risk prevention; • Raise awareness of local exposure to hazards; • Empower and educate local stakeholders to build resilience; • Strengthen social capital, mutual relationships and trust among citizens, scientists, and local authorities;	Parajuli et al. (2020) Pandeya et al. (2021) Rossi et al. (2022)
Absorb	Collect data regarding people's behaviour, attitudes and perceptions during hazards events	• Assessment of hazards social impact; • Development of specific emergency and recovery measures; • Development of tools to facilitate decision-making processes during a disaster; • Empower and educate local stakeholders to build resilience; • Strengthen social capital, mutual relationships and trust among citizens, scientists, and local authorities;	Mahajan et al. (2021) Zhao et al. (2021)
Recover	Collect data about the lived experience of those directly impacted by disasters, as well as coping measures in place	• Development of recovery plans aligned with local context; • Contribute to community preparedness to hazards and capacity to take protective measures; • Empower and educate local stakeholders to build resilience; • Strengthen social capital, mutual relationships and trust among citizens, scientists, and local authorities;	Thomas et al. (2016) Alves et al. (2021) Stablein et al. (2022) Stone et al. (2014)
Adapt	Collect data on potential unforeseen hazards	• Design of mitigation measures to deal with potential hazards; • Empower and educate local stakeholders to build resilience; • Empower and educate local stakeholders to build resilience; • Strengthen social capital, mutual relationships and trust among citizens, scientists, and local authorities;	Zeng et al. (2020) Vadjunec et al. (2022)

Impact of CS projects on community resilience abilities.
Source: Author's own elaboration
Tab. 3

ing citizen scientists' observations with mobile phone technology, making knowledge creation multidirectional, easy to use and access, fostering the mitigation during a disruptive event, natural or otherwise. This comparison suggests that citizen science complements big data by adding contextual and community-based insights that large-scale datasets alone cannot capture, thereby reinforcing its unique contribution to resilience research.
Beyond their academic relevance, the findings of this review also raise important practical and political implications. Citizen science initiatives can support decision-makers by generating locally grounded evidence for resilience planning, while at the same time empowering communities to become active stakeholders in risk governance. By creating spaces for collaboration between citizens, scientists, and institutions, such initiatives have the potential to foster trust and social capital, thereby enhancing both the legitimacy and effectiveness of resilience strategies. Politically, the integration of citizen science into resilience frameworks highlights the need for policies that actively value community knowledge, allocate resources for participatory practices, and address inequalities in access to scientific processes.
Table 3 summarises the main findings of the sample analysed.

Conclusion

CS approaches show great potential to contribute to the development of community resilience's abilities. For this, CS approaches enable the collection of data from new sources or remote places where data is scarce, as well as historical data that is not recorded, allowing for a better characterization of potential hazards, and the identification of community needs, perceptions and behaviours. As a consequence, a more accurate understanding of local context and community's characteristics will be generated, enabling the development and implementation of more effective early warning systems, tools, and mitigation measures.
In addition to data collection, the use of citizen science approaches also impacts community resilience by enhancing community awareness

and knowledge about hazard protection (Rossi et al., 2022), which then improve their capacity to take protective action, such as coping and adaptive measures. The increase in human and social capital is also fostered in CS through specific training initiatives, related with data gathering, data processing and validation, and, thus, increasing community's capacity to take measures towards hazards.

Moreover, CS approaches promote the cooperation between community (citizens), academia (professional scientists) and government (policymakers). This is relevant for the development of public policies shaped to local context and aligned with community's needs and expectations (Mahajan et al., 2021).

In sum, through the implementation of this citizen science initiative, community members were able to increase their understanding of their environment, establish community leaders, grow local networks and improve communication between the community and local authorities, making them better prepared for future challenges.

Limitations

The present study was based on a qualitative and exploratory research method. Despite the well-known limitations related to the generalization of results in this type of approach, the possibility to explore very complex and understudied processes, such as the promotion of community resilience, clearly outweighs the disadvantages. The set of qualitative studies examined provided valuable information on several facets of CS phenomenon, thus contributing to setting the bases for quantitative studies in this area.

Furthermore, the present study only included peer-reviewed articles published in English, which may have led to the exclusion of relevant articles from the analysis. Finally, there may have been some bias related to the content analysis due to the personal views of each researcher. However, an attempt was made to minimize this bias through the individual evaluation of the articles, followed by a consensus discussion where the researcher and a research assistant tried to reach an agreement regarding the classification performed.

Further Research

As noted by Stablein et al. (2022), it is important to explore and understand what role citizens and scientists can play in supporting community resilience. Therefore, there is the need for more transdisciplinary and integrative research approaches to explore the different facets of community resilience, as well as to identify the main barriers and drivers in the implementation of CS approaches.

It is important to note that the findings of this review reflect the current state of the literature, which is still limited in terms of studies addressing more engaged forms of citizen science, such as community-driven or extreme citizen science. While contributory approaches appear more frequently in the analysed sample, this should not be interpreted as a lack of relevance of more participatory models, but rather as an indication of a gap in the existing research. Future studies could therefore explore these more engaged forms in greater depth, as they hold significant potential for strengthening resilience and advancing participatory approaches in risk governance.

Finally, further research should promote quantitative analysis and cross-community comparisons to deeper the understanding of the resilience in the context of territories and communities.

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