A digital ecosystem as an institutional field: curated peer production as a response to institutional voids revealed by COVID-19

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This paper investigates the ecosystem dynamics of the Open-source [COVID-19] Medical Supplies network that arose to fill the institutional void revealed by state and private sector failures to stockpile and supply enough personal protective equipment. Theoretically, the paper adds correctives to extant institutional theory accounts of entrepreneurship filling institutional voids, showing that these can be filled rapidly and normatively by digital entrepreneurial ecosystems allied with peer production networks. These were able to transform the boundary conditions of a routinized system, refixing its autopoesis innovatively. The COVID-19 epidemic galvanized hundreds of thousands of volunteer “makers” around the world to cooperate to meet urgent demand for medical supplies. A digital entrepreneurial ecosystem arose in response to the problem of critical equipment shortages, connecting global, expert-curated know-how with local production equipment. We contribute to the theory of institutional voids by documenting and analyzing how the formation and emergent processes that created and sustained a Digital Peer Production Ecosystem based on self-organization, expert curation and scalability, successfully catalyzed local initiatives worldwide. Institutional voids are not just barriers to entrepreneurship; they are also opportunities.

1. Introduction

Institutions are socially constructed constraints structuring interaction and when institutional frameworks fail to structure appropriate actions, institutional voids can emerge (Khanna and Palepu, 2006). Market-related institutional voids occur when existing “specialist intermediaries, regulatory systems and contract-enforcing mechanisms” (Khanna and Palepu, 2006, p. 62) are exposed as
deficient. Cao and Shi (2021) regard institutional voids as key barriers for entrepreneurs; we argue that voids revealed by a crisis can also present opportunities for a transient, digitally mediated entrepreneurial ecosystem (EE) to form rapidly and build network-based trust for the large-scale production of goods by informal, mostly volunteer actors.

**Purpose** has recently been constituted as a key concept in management and organization studies, especially in terms of the increasing salience of “expressive organizations” (Clegg et al., 2021, p. 13). A theme in recent literature is that COVID-19 created an institutional void that promoted entrepreneurial agency fuelled by expressive social purpose. For instance, Chesbrough (2020) highlighted the importance of open innovation as a rapid response to the voids that the pandemic revealed; the same rapid response is evident in the 21 Italian firms discussed by Ferrigno and Cucino (2021). These firms’ “purpose-led, nonprofit objectives” drove their “innovation efforts to provide societal benefits” (Ferrigno and Cucino, 2021, p. 11). Using the biological concept of exaptation, Liu et al. (2021) researched 80 cases of ecosystems that exhibited design capability and manufacturing flexibility in responding to the crisis with accelerated innovation. Liu et al. (2021) demonstrate that social purpose alone is insufficient; in addition to design capability and manufacturing flexibility clustering must occur in a community of social purpose that, as we elaborate, can be created rapidly and effectively through digital affordances. Such affordances can rapidly innovate the conditions under which the autopoiesis (Luhmann, 1986) of a system occurs. When autopoiesis occurs, both internal and external conditions are produced simultaneously. Under extreme pressure, refixing of the boundary of the system can occur, as this paper will narrate.

Despite a wealth of research on the EE of Silicon Valley and its clones (Alvedalen and Boschma, 2017), Digital Entrepreneurial Ecosystems (DEE) without a geographical basis have been largely overlooked (AUDRETSCH et al., 2019). Only recently have scholars begun to engage with them (ACS et al., 2017; Nambisan, 2017; Sussan and Acs, 2017; SONG, 2019). With the increasing adoption of digital platforms, a novel ecosystem of economic activity emerges in which actors are spatially and temporally distributed, yet engaging in entrepreneurial opportunity, discovery and pursuit. In these ecosystems, digital platforms are repurposed to engage actors in co-innovation through mechanisms of ideation, collaboration, and communication (Abhari et al., 2017). Digital ecosystems using the affordances of the Internet offer a transversal perspective on the nature of business ecosystems (Scaringella and Radziwon, 2018). Hybrid open collaborative networking (Chesbrough, 2006) enables a variety of stakeholders to interact strategically without the steering capacity of a single firm (Dabrowska et al., 2019, p. 4) or government. Accelerators, living labs, social innovation labs, open labs, and community makerspaces can deliver both business value and societal impacts (Silva and Wright, 2019).

The paper introduces a type of DEE devoted to the production of physical goods: a Digital Peer Production Ecosystem (DPPE). The DPPE consists of digitally connected, interdependent actors with shared commitment, who directly and indirectly support the creation and growth of new products. In contrast to industrial production, “Peer Production” relies upon small-scale manufacturing by a distributed network of “peers” who are often hobbyists, purpose-driven volunteers and other non-experts (Maxigas and Troxler, 2014). This analysis focuses on the ecosystem dynamics of the Open-source [COVID-19] Medical Supplies (OSMS) DPPE, which formed to meet a critical need for personal protective equipment (PPE) manufacturing in the early stages of the COVID-19 pandemic. In addressing the mobilization of OSMS, we theoretically analyze how an institutional void whose existence became apparent and critical during the pandemic, was filled via the creation of a DPPE.

In the wake of failures by the state and industry to supply sufficient PPE, the COVID-19 epidemic entrepreneurially galvanized hundreds of thousands of volunteer “makers” around the world to cooperate to meet urgent demands for healthcare supplies (Pearce, 2020; Cavalcanti et al., 2021; Rossi et al., 2021) in a market whose supply chain complexities are many (Marques et al., 2020). Voluntary efforts joined by strangers with little or no former connections transformed into digital discussions and collaborations around product design and production. These were not place-based, profit-driven entrepreneurial ecosystems but a “translocal” and purpose-led pandemic relief ecosystem (Schmidt, 2019; Corsini et al., 2020) of collective and conjoined institutional entrepreneurship. These collective efforts were based on a “process of self-organization” (OSTROM, 1999) across shared and open resources and facilitated by the thousands of makerspaces, hackerspaces, fab labs and other “Open Creative Labs” (SCHMIDT, 2019) that bridge local, regional and global scales through digital networks.

These entrepreneurs were simultaneously inspired by an economic shortage of supply of PPE creating an institutional void as well as by an overwhelming sense of purpose in seeking to limit the ill-effects of COVID-19, the ‘social need’ (Mair and Marty, 2006).
they addressed. They were entrepreneurs in several senses. First, they responded to economic shortage of supply and imaginatively, creatively and rapidly responded to meet sudden market demand. They did do by becoming part of an entrepreneurial ecosystem connecting global designers and fabricators through digital networks. Second, their network formation in a disembedded space, united only by a sense of the social value that they could contribute through the ecosystem they were forming (Carriles-Alberdi et al., 2021), was also entrepreneurial. Finally, they were entrepreneurs in the Schumpeterian sense of social engineering identified by Zahra et al. (2009). They sought to innovate more effective social systems designed to replace existing supply chains and just-in-time provision when it proved to be ill-suited to address significant social needs.

Our paper investigates the emergence of this DPPE in terms of its success in catalyzing local initiatives worldwide, asking (1) how the institutional field comprising a digital ecosystem was formed and (2) what processes did it use to fill an institutional void and achieve legitimation through curated peer production networks? Our work bridges research on peer production and the maker movement with EE literature, as we describe how a DPPE created and gained legitimation for a new institutional field of open-source responses to a critical event exposing an institutional void. In drawing on institutional theory, our contribution provides understanding of collective micro-dynamic institutional entrepreneurship (Maguire et al., 2004) enabled by the digital realm. We highlight the importance of the informal open-source ecosystem in creating rapid legitimacy, signified by adoption by formal healthcare institutions and spotlight the centrality of digitalization to the field’s emergence. We also show how informal actors acting as networked institutional entrepreneurs can affect development, without occupying central positions in the existing institutional field of multinational medical-related firms or government regulators; instead, working from many marginal areas, they were able rapidly and radically to transform the institutional voids for PPE that these firms and regulators had unwittingly created in the face of a pandemic. Furthermore, we contribute to the ecosystem literature by revealing the emergence of an informal and transient DPPE following temporary institutional voids.

2. Digital entrepreneurial ecosystems and expert-curated peer production

The connection to a digital ecosystem of commercial and academic experts is a key factor in scaling up a DPPE’s informal, small-batch production and demonstrating the network’s shared commitment to harnessing scientific and technical knowledge. We call this diverse community of practice a curated peer production ecosystem.

As DiMaggio (1988) proposed, the relationship between interests, agency and institutions is central: “New institutions arise when organized actors with sufficient resources (institutional entrepreneurs) see in them an opportunity to realize interests that they value highly” (DiMaggio, 1988, p. 14). As Maguire et al. (2004) explain, successful institutional entrepreneurs identify opportunities, frame issues and mobilize constituencies (in line with Rao et al., 2000, p. 240) to engage the “activities and interests of other actors in a field, crafting their project to fit the conditions of the field” (Maguire et al., 2004, p. 658). Typically, prior to Maguire et al. (2004), it was dominant actors holding powerful subject positions that were seen as institutional entrepreneurs; they argued that the HIV/AIDS crisis transformed characteristics of emerging fields riddled with uncertainty in the institutional order. More controversially, in our view, they propose that.

Isomorphic pressures will be less relevant if there are no established patterns or leaders to mimic; the widely shared values associated with normative forces have yet to develop (…). Consequently, institutional entrepreneurs in emerging fields must devise and maintain stable sets of agreements in ways that meet the interests of diverse stakeholders and without access to the taken-for-granted symbolic and material resources and institutionalized channels of diffusion that are normally available in mature fields. (Maguire et al., 2004, p. 659)

We argue, against this hypothesis, that the COVID-19 crisis enabled the creation of a DPPE institutional field rapidly, normatively and innovatively rather than mimetically, not through ‘stable sets of agreements’ but through non-institutionalized, informal ‘channels of diffusion’ which rapidly formed in the early months of COVID-19 to produce PPE and then dissolved as global supply chains pivoted to make up for prior institutional voids. Digital social platforms enabled the creation of a curated peer production network in ways that normal institutional structuration could not provide. Thus, what is distinctive about our case is the rapid emergence of a co-constructed, transitory institutional framework to support the DPPE in its purpose of addressing vital equipment shortages. Technical and digital capabilities combined with passionate ‘normative forces’, rather than ‘coercion’, enabling these capabilities to be used to help combat the
greatest global health challenge of contemporary times. The legitimation of this DPPE was eventually provided by key regulatory institutions, but the important point is that they did not promote, sponsor or resource the peer production that occurred because of the DPPE.

3. Methods

A pandemic health crisis mobilized rapid research responses globally, including management research (Chesbrough, 2020; Ferrigno and Cucino, 2021; Liu et al., 2021; Passetti et al., 2021). As Beech and Anseel (2020, p. 447) noted, “COVID-19 has provided an ‘electric jolt’ to research, with many academics taking a problem-oriented approach seeking to address the challenges associated with COVID-19 … researchers are starting to conduct research with business and society.” It is this approach that characterizes our work, which employed both secondary and primary data, to explain how entrepreneurs used digital affordances to create a platform for collective institutional entrepreneurship as a response to the shortage of PPE in the pandemic.

3.1. Data collection

Our primary source material consists of the public contents of the OSMS Facebook group from December 2019 through to June 2021, which provided around 7,000 pages of posts and comment threads which are cited anonymously as OSMS Facebook (2021). Secondary sources were drawn from reports, media interviews, scholarly papers and the OSMS community report based on multiple surveys (Cavalcanti et al., 2021).

Our direct involvement in and support of the community under academic investigation follows the tradition of Participatory Action Research (McIntyre, 2007); while engaging with participants and observing relevant discussions throughout 2020, we contributed our own expertise to assist with PPE production efforts in the U.S., Portugal, and India by providing introductions to relevant actors and makerspaces, participating in discussions on Facebook and Slack and joining video calls with OSMS organizers.

3.2. Data analysis

We sorted and analyzed posts from the OSMS Facebook group by identifying discourse with the most comments and reactions (“likes,” hearts, etc.) to serve as representative case studies using Crowdtangle, a public insights tool owned and operated by Facebook. We used an iterative analysis of these conversations to identify themes, combined with rigorous consideration of secondary data and our own Participatory Action Research in the digital “field” (McIntyre, 2007) which allowed the authors to identify trends over time. We have pulled this material together by arranging our findings using a narrative methodology (Elliott, 2005) that organizes events into a sequentially ordered whole.

Our different information sources, as well as our own direct engagement with participants, helped us in two ways: first, we were able to gain a comprehensive understanding of the phenomenon; second, we were able to triangulate our findings from the different sources. Some of these observations are selected as in-text vignettes, while in Appendix A we provide some selected evidence of the themes emerging from our qualitative evidence.

4. Findings

4.1. OSMS and the emergence of a digital peer production ecosystem

A digital ecosystem was formed as an institutional field in a rapid response process to the shortage of critical equipment to combat the pandemic. OSMS started as a Facebook post about medical supply chain shortages by American makerspace founder and entrepreneur Gui Cavalcanti in March 2020, which generated enough enthusiasm that Cavalcanti and several of his colleagues started a new Facebook group. On 11 March 2020, one day after the group launched, its administrative team identified and interviewed COVID-19-trained healthcare workers as to the types of supplies needed; this was also the day the WHO declared a pandemic. OSMS began sharing responses on Facebook and preparing a Medical Supply Guide to inform its exponentially growing community. Maker and fab lab communities, in addition to medical professionals and hitherto un-affiliated hobbyists, were joining dozens of Facebook groups, Slack channels, Github projects, and other open forums in the first days of the pandemic. The strength of weak ties (Granovetter, 1973) came into play as social media algorithms prioritized posts related to COVID or PPE made by the friends of participants, who joined the OSMS group as well. Segregated peer production silos (Menichinelli, 2016) disappeared in the face of the crisis and OSMS emerged early on as a trustworthy and reputable source of information around PPE, as well as a forum for designers and producers to engage directly with expert medical professionals.
OSMS was rapidly creating a digital community of practice using both synchronous and asynchronous communications technologies to construct meaning collaboratively, in an innovative display of institutional entrepreneurship. By 21 March 2020 the group had acquired 33,000 members and doubled in size the next week. Engagement grew quickly, tapering with connections made to the broader ecosystem. That week, the group received 105,085 post interactions, constituting 52% of all the group’s interactions through June 2021. In mid-May 2020, the group hit its peak of 73,800 members (analysis performed through Facebook’s CrowdTangle 2021). Nonetheless, Cavalcanti estimates that only about 1,000 people were particularly active in designing and redesigning actual products, which is a typical ratio for peer production.

By May 2020, a DPPE emerged, spearheaded by OSMS and its partner organizations, consisting of six key components facilitating expert-curated peer production:

1. A formal organization, which for the summer of 2020 had 19 full and part-time employees: 2 co-executive directors working on OSMS full-time, 3 professionals on medical research, 4 people on local response and 10 split between documentation, communications, and technology. OSMS organized under an umbrella non-profit fiscal sponsor based in California.

2. Curated OSMS Project Library, detailing manufacturing instructions for 200 unique designs across 35 different medical supply categories, a curated repository of wisdom. Most were manufactureable in small batches using hobbyist makerspace/fab lab equipment costing a few thousand dollars (USD): sewing machines, 3D printers, laser cutters and basic electronics. Community-submitted designs filtered through OSMS’ curation and vetting pipeline, where they were verified by medical professionals before top designs were chosen for publication.

3. Eight informational briefs compiled by OSMS directors and staff experts for specific circumstances (school safety, N95 mask reuse, etc), with professional design/illustration and expertise and translations to multiple languages.

4. One moderated Facebook group with a peak of 73,800 users and roughly 7,000 accumulated pages of posts and comments and one moderated Slack group with ~1,300 users and 37 public channels to provide feedback on design, testing, materials, manufacturing and emotional support creating information dissemination and potential introductions/networking.

5. Eight hundred and ninety five registered, loosely affiliated regional “Citizen Maker Response” groups worldwide, which operated their own local platforms across Facebook, Slack, WhatsApp, physical makerspaces, etc.

6. Several centrally coordinated matchmaking platforms to request and provide PPE at the local level, such as the FindTheMakers map with 3,865 requesting organizations worldwide, as well as the US-only Get Us PPE website with over 20,845 individual requests made, distributing 7 million items of PPE as of February 2020 (Get Us PPE, 2020).

As shown in Figure 1, these components coalesced into a volunteer led DPPE, with the shared mission of distributing PPE and safety guidance globally; in the process filling an institutional void through distributed institutional entrepreneurship.

By January 2021, the OSMS DPPE had produced 48.4 million units of PPE across 86 countries – with around 94% of participants volunteering their labor (Cavalcanti et al., 2021). Yet the network was transient; by January 2021, around 72% of U.S.-based OSMS participants reported slowing down production primarily due to decreased local demand for PPE (Cavalcanti et al., 2021) and the OSMS Facebook group pivoted from COVID-19-specific supplies to medical supplies more generally.

4.2. Rallying around a shared mission

The processes that were used to fill the institutional void created by the global need for far more PPE than traditional supply chains could deliver, were achieved through a combination of normative and technical affordances. Normatively, a multitude of independent but digitally connectable practitioners were motivated by a strong social purpose to help fight the coronavirus. Doing so independently would not achieve much; what gave social purpose legitimacy and connection was the existence of curated peer production networks.

The open-source hardware community’s everyday inventiveness and extensive global collaboration, from Linux software to affordable 3D printers, biology lab equipment, modular houses, prosthetic hands, tractors and plastics recyclers, is legendary (Von Hippel, 2017). Nonetheless, OSMS and related efforts mark the first time an open-source community galvanized around a shared, global mission to achieve the coordination and manufacturing of mass production unprecedented in past peer production. Most participants credited the coherence of the emergent digital ecosystem as the reason for its success (Cavalcanti et al., 2021). Table 1 below illustrates how the extended OSMS maker
community differs from prior Maker efforts, leading to the creation of a new category of entrepreneurial ecosystem: a digital peer production ecosystem (the DPPE) that establishes trust through expert-curation.

OSMS Facebook group participants in week two initially expressed concern about organizational incoherence: “Guys, lets collect info about what can YOU help with, in what capacity and your location” (OSMS Facebook Post, March 2020). The post received 414 comments, from healthcare workers requesting specific items, to individuals offering their personal sewing machines, 3D printers and design expertise to the cause. Two days later “[We’re] at 30 k members – is it time for local groups that understand local needs?” was posted.

Following an enthusiastic response, the original poster reported: “We’re at 45 k members – mention your local group that understands and contributes to local needs!” The post received 343 affirmations and 475 comments from loosely affiliated OSMS groups worldwide. Soon after, OSMS established translation teams to localize design guides and briefs.

Aware that networking attempts across thousands of Facebook posts and comments would quickly be lost in the noise, early OSMS members rallied to create (1) regionally specific “Local Response Groups” connecting local needs and coordinating local supply chains, as well as (2), OSMS’s dedicated channels on Facebook and Slack discussing topic-specific items of PPE and/

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**Figure 1.** The actors of OSMS constituting an expert-curated DPPE.

**Table 1.** OSMS as a DPPE-facilitating expert-curated peer production

|                      | Open-source hardware, pre-pandemic | OSMS, during the pandemic |
|----------------------|-------------------------------------|----------------------------|
| Digital              | Scattered, non-coherent online and offline efforts | Coherent regional, national and global digital communities united by OSMS and other aggregators |
| Entrepreneurial ecosystem | Design and flexible manufacturing using digital fabrication; occasional small-scale coordination | A global digital platform, functioning as a beacon and an attractor of expressive social purpose to fill an institutional void that rapidly became evident in the supply of essential PPE during COVID-19’s early onset in an example of collective, unified institutional entrepreneurship |
| Expert-curated       | Many different repositories that may or may not be vetted by experts | Several shared repositories, curated for salience and quality in coordination with medical experts and end-users |
| Peer production      | Mostly craft production of many different products | Distributed mass production of similar types of products |
or processes. OSMS began a page collecting these regional groups on their website, allowing the executive team to network cross groups and share relevant introductions more formally. OSMS staff wrote a Local Response playbook, starting out as a collaborative Google Doc, eventually solidifying into an interactive website encouraging independent action and initiative.

### 4.3. Curated peer production producing medically legitimate PPE

As OSMS participation exploded and began implementing this federated coordination model, a problem arose that is common across networks in which non-expert volunteers act before they know what is needed: medical professionals complained that hobbyists were wasting time on trivialities or even endangering COVID-19 patients through ill-conceived aid. Making things that did not work or meet clinical standards was of little value or legitimacy. One anesthetist on the Facebook group thanked “everyone for your enthusiasm but please temper it with some thought of actual clinical utility” (OSMS Facebook March 2020), providing extensive guidance on specific innovations useful for mitigating the shortage of ventilators. Initial Facebook and Slack discussions had focused on a wide variety of potential products, especially ventilators and 3D printable N95 masks. DIY ventilators were difficult, if not impossible, to bring into hospitals because the shortage turned out to be one of skilled ventilator operators rather than machines, with ventilators being used less than initially anticipated for resuscitation. Through digital conversation with healthcare workers found through the network, OSMS inventors switched from DIY ventilators to 3D printable ventilator splitters and DIY oxygen concentrators.

Well-publicized admonitions from medical professionals also encouraged users to stop making useless 3D printed parts and focus instead on critical needs (e.g. “Hi I’m an emergency doctor. Please stop printing ‘valves’. Unless you are actually in contact with a specific hospital and they are telling you they need that exact part, you’re just using up filament” (OSMS Facebook March 2020)). Later OSMS Facebook and Slack discussions focused on medically rated N95s and safe practices around N95 reuse to help frontline workers curb infections, rather than producing safety-critical surgical supplies for which informal producers could not provide safety guarantees. Generally, many OSMS producers pivoted from inventing new ideas to mass-producing less exciting but more feasible supplies such as face shield holders, cloth masks and “ear saver” mask clips following clear demand signals from healthcare professionals. Accolades and gratitude from recipients worldwide occurred; hospital workers routinely posted photos on Facebook wearing OSMS-made PPE and holding up thank you signs.

### 4.4. Local and national worldwide coordination

A neglected important characteristic of ecosystems is that of coordinating interrelated organizations with significant autonomy. This self-organizing capacity of heterogeneous actors is consistent with both EEs and a digital EE (Sussan and Acs, 2017). OSMS rarely sought to dictate one design or one verified production method (Corsini et al., 2020). The goal was facilitating collective localization and networking for thousands of loosely connected, local initiatives, this goal was enabled through the development of the DPPE.

In India, a seven-year-old makerspace called Maker’s Asylum founded the country-wide COVID-19 response initiative M19 Collective. Within a month and a half, M19 organized makerspaces across 42 Indian cities, producing over 1 million face shields. Maker’s Asylum provided the face shield design and manufacturing expertise, producing 135,000 face shields in its own facility and launched an Indian-wide movement through personal contacts, adding around 100 local leaders to a private WhatsApp group coordinating marketing videos, outreach and production and distribution. During the peak of production, Asylum received 100–200 calls per day from labs and hospitals, dedicating a staff member to communications full-time. Scale and coordination of collective effort were critical to successful growth during India’s severe lockdown. Indian government bids were won through public tender. To comply with lockdown requirements, M19 obtained PPE demand letters from city officials to ship supplies across regional borders, working with hospitals and local governments to ship PPE through off-duty ambulances and police cars rather than personal vehicles (Corsini et al., 2020; OSMS, 2021a).

In Minnesota, USA, the KnightKrawler high school robotics team collected 3D printers and donated materials from local industries to design an assembly line from robot parts—culminating in 37,000 face shields for their community (Cavalcanti et al., 2021). Across Spain, physical makerspaces and digital 3D printer communities formed a national network of 16,500 members to coordinate with medical professionals to make and deliver over one million face shields (Sáez and Cuartielles, 2020).

The combined strength of the OSMS network facilitated maker collaborations with regional and national
policy makers. Czech inventor Josef Prusa developed an early open-source face shield design which received Czech Ministry of Health approval on March 16, 2020. Days later, an American non-profit downloaded the CAD files and 3D-printed the Prusa RC1 shield for the Infection Control Department at the University of Washington Harborview Medical Center in Seattle. Additional protection over the forehead led to a modified design approved for American clinical settings through expedited review by the US National Institute of Health on March 28. Prusa later acquired a European Union CE certification for 3D printing shields on his factory’s printers, publishing directions to help others obtain certification for their makerspaces (Cavalcanti et al., 2021). On April 9, 2020, the US FDA issued their first temporary Emergency Use Authorization to allow hospitals to use non-certified face shields for medical use, provided the face shields complied with guidelines and labeling requirements (Hinton, 2020). Authorization “opening the door for hospitals and other medical institutions to accept supplies from the maker community” (Cavalcanti et al., 2021, p. 24), an event that was vital to legitimization of the burgeoning institutional field; by January 2021, the OSMS network had produced 25 million face shields.

Following the success of OSMS, the U.S. National Institute of Health decided to accept laypeople’s designs for their medically reviewed 3D Print Exchange. When their platform experienced a 6,000% increase in unique visitors to the site within a day of inviting makers to upload submissions, they lacked capacity to meet demand for medical expertise. The website crashed. Following this, three government agencies collaborated with the national 3D printing Manufacturing USA Institute to form the COVID 3D Trust in January 2021 to professionally compile, test and evaluate 3D-printed PPE for clinical use (VHA 3D Printing Network COVID-19 Response, 2021). Along with their final status report, the OSMS team published a policy brief guiding the United States government in how to host a national digital stockpile of approved designs for medical supplies, in case of future pandemics.

4.5. Open network responses in the ecosystem

Small-batch demand is the bane of modern supply chains; mass manufacturers are uninterested in wasting their time fulfilling order volumes below a certain quantity, while capable makers lack manufacturing capability and supply chain knowledge to scale up to larger batch sizes. The OSMS survey reveals that 92% of participating non-hospital institutions (including nursing homes, schools and essential businesses) could not afford to meet the minimum order size of large manufacturers, so they turned to makers; a full 92.4% of OSMS makers fulfilled requests with fewer than 150 units per order (Cavalcanti et al., 2021).

Many supply chain challenges were overcome through individual Facebook posts to the OSMS group, such as the following: “My research lab is currently exploring means to mass produce face shields and face masks. However, we are experiencing difficulties with obtaining supplies such as filters, transparencies, and elastic bands quickly. Could you guys help us with locating reliable suppliers for these materials? Thanks a lot!” (OSMS Facebook April 2020). This post was tagged #Help Needed and received 28 comments – including two offers of shipping large quantities of face shield plastic within the feed. Elsewhere, in Brazil, the Olabi makerspace network facilitated supply chain matching with a tracking system called ProtegeBR. This publicly available platform lists 108 public health offices throughout Brazil and provides contact information for each facility, in addition to listing contact information for over 250 maker initiatives nationwide. This network distributed over 1 items to healthcare workers (OSMS, 2021b).

5. Discussion

Prior to the pandemic, open-source and peer production communities tended to focus on “economies of scope, not of scale”, including user creation, customization, and shared intellectual property (Commons Transition Primer, 2017). Collaborations across entire countries, especially involving governments and regulatory authorities, were encouraged but rarely scaled up globally. During the COVID-19 crisis formal organizations, both public and private, were ill-prepared for dealing with the critical shortages that rapidly emerged. It was global networks of informal suppliers, makers, designers and users virtually mediated by the affordances of the Internet that provided an effective initial response to the crisis.

The crisis revealed an institutional void that was not apparent in ‘normal’ times. The pandemic affected global supply chains as workers across the production chain had to self-isolate and many nations banned exports of critical materials, causing large scale shortages of key items such as PPE usually supplied by multinationals. The pandemic caused a huge surge in the demand for PPE products globally, resulting in widespread shortages. For the future, hospitals and other health care facilities will have to do one or other of two things. First,
either develop more storage capacity for when the next global health crisis occurs or second, maintain relations with a repository of key DPPE networks and the platforms that enable them to draw on as reserves for short-term solutions. While the next global health crisis may not be a coronavirus, its impact on health workers will create abnormal demand for PPE that will not be satisfied by global producers’ economies of scale for just-in-time supply.

There are wider lessons to be drawn. Random environmental contingencies that disrupt global supply chains, such as pandemic viruses, can occur with little notice. When they do, normalcy, however it is constituted, will be disrupted. Such disruptions reveal the fault lines that can be globally induced by stress tests having the magnitude of highly contagious viruses. Under these conditions, standard approaches to innovation can rarely assemble the rapid responses required. What are needed are global–local innovations, global in their digital virtuality and local in their affordances to innovate solutions to the institutional voids that the global event, the pandemic virus, reveals. In such contexts, global networks of local entrepreneurial action can sustain sophisticated systems when the capacity for autopoiesis, to reproduce and organize through closed systems of self-referential communication that constantly reproduce and evolve via the repetition of their own operations, fails.

For Luhmann (1986), an autopoietic system produces itself while simultaneously producing its own conditions, both internal and external. It does so largely through routines. Where repetition fails because of events that disequilibrate everyday operations stabilized on strategies of just-in-time and tightly coupled supply chains, these can collapse at any point, whether in production or distribution, caused by pandemic contagion and state responses to the unprecedented events, such as lock downs. When routines are disrupted by events, the boundary between a system and its environment must be innovated if system failure is occurring and the system is to survive. The most critical link in the supply chain to end users proved to be the supply of protective equipment keeping healthcare staff and patients as healthy as possible in the face of a virulent and novel virus, whose transmission was airborne. Under these circumstances the creativity of innovation under pressure of temporal disruption, escalating demand and supply disorganization, came to the fore, through global digital affordances and local fabrication using these affordances.

A DPPE of mostly volunteer global actor networks innovated to hack or build tens of millions of PPE items, something unprecedented in the history of peer production. While it was “mass production”, it was not produced in the traditional sense of identical products, materials and production strategies. Instead, collaborations around curated designs and production emerged from the DPPE sustaining expert-curated peer production. Scalability, speed and modularity (Flyvbjerg, 2021), the latter in terms of replicable designs meeting regulatory requirements, were essential to success. Decentralized networks gained efficiencies from incorporating diverse actor specializations, defined as deep domain knowledge, applicable at the local level (Carney, 1998; Shank and Govindarajan, 2004).

Our findings contribute to the theoretical literatures on open-source communities of practice and EE. In an extraordinary crisis, the ingenuity of the multitude speedily and effectively provided practical succor faster to market than oligopoly suppliers’ protective patents and extended supply chains. In consequence, the DPPE collectively, entrepreneurially constructed a new institutional field, one with major practical implications for autopoiesis. The DPPE framework, bridging between the Peer Production/Maker Movement literature and EE, facilitated a self-organized, mass production network that existed entirely outside the bounds of the existing firm’s supply chains and just-in-time provision. The ecosystem resulted from a digital platform-enabled institutional entrepreneurship, allied with distributed local normative isomorphism prior to being granted regulatory legitimation. There was no single institutional entrepreneur but a mass and distributed entrepreneurial network enabled by digital platforms, which reconstituted the autopoiesis of the system.

What was distinctive about the DPPE emergency response in practice, was that it was not single site-specific as well as being forged in a common purpose. The ecosystem overrode already embedded global supply chain systems as actors united in a common purpose to provide material aid as rapidly as possible. Most of the peer production networks that arose in response to the ecosystem felt that making a profit was secondary to value commitment; as Chalet et al. (2020) noted, volunteer efforts during the pandemic were more effective than governments or markets in mobilizing short-term production, doing so through self-organization. This underlines the diversity of goals that are comprised by different types of EE that reach much beyond a profit-seeking rationale, and a shift toward social and sustainable value creation that is prompting scholars to rethink the EE concept (Cobben et al., 2022). The temporary nature of this ecosystem and its networks, also
challenges more ‘conventional’ assumptions of EE literature regarding EEs’ evolution trajectory (Mack and Mayer, 2016), and notably challenges the incumbent supply chains. It was possible to create an ecosystem of actors through digital affordances that were able to plug vital gaps in global supply chains locally, by drawing on globally shared expertise and networks. A viral self-managed network, spread as a digital web of affordances, was utilized to assist the management of a viral pandemic that was far less positive in its practical implications.

When the global crisis of COVID-19 inspired disparate maker communities to close gaps in medical supply, they proved capable of achieving the scale of mass manufacturing through distributed small-batch production en masse. Localizing resource flows changed the geography of globalized production through novel technological systems and strategies (Johansson et al., 2005). Instead of imposing one-size-fits-all solutions from the top-down, OSMS’s DPPE facilitated a network of legitimate expertise, incorporating medical specialists, materials scientists and government regulators, allowing solution sharing and remixing of global ideas for regional needs. In addition, open-source networks demonstrating “small-world” effects combined the benefits of a small pool of contributors with the global scale of thousands of loosely coupled initiatives (Singh, 2010). More effective, distributable problem-solving and greater communication across the DPPE transpired (Latora and Marchiori, 2001; Uzzi and Spiro, 2005).

6. Conclusion and future work

We investigated an informal EE that emerged through digitally enabled, conjoint expressive social purpose, linking design and manufacturing flexibility in a DPPE at a time when normal institutional structuration was unable to meet demand for PPE during COVID-19. In contrast to dominant arguments in the literature of institutional entrepreneurship, this DPPE rapidly created a new institutional field for R&D, normatively and innovatively, rather than mimetically, not through ‘stable sets of agreements’ but through non-institutionalized ‘channels of diffusion’ of curated peer-production. R&D, on scale and with rapidity, was enabled by the affordances of a digital hub and an extensive network of peer production. It was non-proprietary, open-source and highly innovative in servicing local and urgent needs with what rapidly became well-designed and appropriate products. It was neither corporates nor individual startups that did the R&D but the ingenuity of OSMS’ creation of a digital hub that created the templates for a global network of peer production. The entrepreneurship was motivated by innovating more effective social systems when supply chains and just-in-time provision failed to address significant social needs for PPE revealed by the pandemic.

In exploring the formation and void-filling activities of this DPPE, we make several contributions to theory that we reiterate here. First, we added to the theoretical understanding of the micro-dynamics of institutional entrepreneurship by providing a more nuanced, contextualized view of the activities of collective institutional entrepreneurship. We highlighted the importance of new practices being accepted through immediate and local normative institutional isomorphism by local users, irrespective of regulatory legitimation of the products produced. Legitimation was initially locally distributed by virtue of meeting immediate needs. There was an absence of any mimetic precedents; only subsequently was the DPPE strategically institutionalized as legitimate by existing systems of institutional legitimacy. Second, we demonstrated that institutional entrepreneurship could affect positive social development without occupying central positions in the existing institutional field of multinational medical-related firms. Third and fundamentally, we highlighted the centrality of digital platforms to the rapid emergence of a curated DPPE. Finally, we contributed to the emerging literature on digital entrepreneurial networks, by showing that institutional voids can create opportunity with the emergence of platform enabled ecosystems, lasting at least as long as the voids persist.

What lessons can we learn from OSMS for the potential of DPPEs to solve other social problems? While the context of a global pandemic urged the ecosystem’s explosive pace of growth, the success of OSMS is potentially replicable on a slower timeframe for different problems. These insights may be useful to deal with different but increasingly common events, regarding the growing instability of international supply chains and sectors of economic activity. The digital network was the ecosystem’s greatest initial asset. Network-building was most active in its first few weeks of existence when participants were in a flurry of crisis-induced networking and communication. By establishing itself from the beginning as a trustworthy forum for makers (the producers), medical professionals (the experts/consumers) and regulators/government officials, OSMS was able to gain institutional legitimacy rapidly. It was this legitimacy that united disparate makerspaces, fab labs and other networks into a community of practice that enabled productive global collaboration while supporting tailored, local initiatives.

Rapid scale-up was essential to meeting the increasingly visible shortages and gaps globally in
PPE availability, as the formally contracted manufacture and distribution of PPE was overwhelmed by the sheer immediacy and scale of global demand. The DPPE meant that global and expert know-how could combine with local resources to deliver and scale-up production rapidly. The key to successful PPE delivery was the combination of expert know-how, globally sourced designs in a curated repository and local delivery. That delivery, from a rapidly emergent field of collective, distributed institutional entrepreneurship, was later legitimized by existing institutional bodies, such as the U.S. National Institute of Health and the Manufacturing USA Institute’s COVID 3D Trust. Without this external legitimation, the ecosystem’s institutional entrepreneurship would not have been formally institutionalized.

There will be other pandemics and other crises in the future, during which the learnings from this case could facilitate future social entrepreneurship platforms (Bozhikin et al., 2019). The most important aspects of the success of the DPPE as a platform were the combination of digital affordances, professional expertise, and a collective sense of purpose oriented toward plugging gaps in a highly specialized and routinized health system. If such an example of institutional entrepreneurship is to be successful in the future, the emergence of this DPPE provides a template for rapid institutional legitimacy of collective, distributed efforts in ecosystem-building. In the event of future crises, while one might wish that health policymakers would make better contingent plans for institutional gaps, the template for an alternate and grassroots response is evident from this research should the need for a DPPE arise again.

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Data Availability Statement
Data would be made available upon request.

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### APPENDIX A

#### Selected evidence

| Local initiatives self-organize around products | Themes |
|-----------------------------------------------|--------|
| “I’ve seen many ventilator projects around the internet but I have not seen a lot of detail on the control systems for these ventilators…” (OSMS Facebook 2020) OSMS creates a local response guide | Digital entrepreneurship; platform-facilitated creativity unbounded by geography |
| “a how-to playbook: a collection of best practices and specific instructions for those organizing PPE and medical supplies production efforts.” (OSMS website 2021) | |
| OSMS launches a map and online network to strength local groups on a global scale | Expert-curated (medical professionals) |
| “Locate active makers, crafters and manufacturers in your region, explore the need for medical supplies in your community, and check your organization’s details.” (OSMS website 2021) | |
| OSMS admins interview healthcare workers about demand needs and publish results | |
| “Medical professionals – we need your input to figure out what is relevant to design and what is not. If you have had COVID19 training specifically, please consider answering the questionnaire in this document.” (OSMS Facebook 2020) | |
| Informal feedback from medical professionals: | |
| “If [N95s] could be made with the pocket they are so helpful, because we all get [only] one, and then have to disinfect it and keep it for our next shift” (OSMS Facebook 2020) | |
| OSMS guidelines for safe schools, businesses, etc. | |
| “This guide incorporates 81 resources from institutions, organizations, case studies, media outlets, and research evaluations from around the world into a single repository … to highlight both effective and ineffective strategies to help educators and administrators plan how best to safely and responsibly return to the classroom.” (OSMS website 2021) | Expert-curated (scientists and engineers) |
| OSMS brings medical professionals onto executive team | |
| “OSMS provides links to projects and information about the utility, availability, and manufacturability of personal protective equipment (PPE) and medical supplies, curated by a global team of medical advisers.” (OSMS website 2021) | |
| Scientific labs repurposed to test products and materials | |
| • MakerMask, USA uses biomedical equipment to test common materials for N95 replacement | Distributed peer production |
| • MIT chemical engineering lab, USA tests imported N95 masks | |
| Hobbyists test products and materials with local experts | |
| • MakerLab, USA tests PAPR materials with local fire department | |
| • Artisans Asylum, USA tests gown materials with local hospital | |
| OSMS develops an internal curation strategy for designs and pipeline for feedback | |
| • Trusted product developers help sift through submitted ideas according to product type, to highlight the best concepts and help design products for manufacturability | |
| • “Is Facebook the best place for this? Should contributors have an easier place to chat/share/pin useful info? Slack or Discord?” (OSMS Facebook 2020) | |
| Shared materials and tools | |
| “I wanted to introduce myself and offer up my printer farm of 12 printers” (OSMS Facebook 2020) | |
| “Could you guys help us with locating reliable suppliers for these [face shield] materials?” (OSMS Facebook 2020) | |
| Customized production for smaller customers | |
| • 92.4% of OSMS respondents fulfilled requests with fewer than 150 units per order (Cavalcanti et al. 2021) | |
| Frontline workers requesting PPE/supplies directly through GetUsPPE.org, etc: | |
| “My Best Friends son … puts people on ventilators at the hospital. So he’s the guy working with all the Covid patients. Yesterday they used their last face mask …. Can you help? we need Halyard H600 sterilization wrap or similar.” (OSMS Facebook 2020) | |