Maker movement contribution to fighting COVID-19 pandemic: insights from Tunisian FabLabs

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COVID-19 is an unexpected and brutal pandemic that requires new innovation models to overcome the constraints of this crisis and address its multiple challenges. Open innovation does not replace a traditional closed R&D model; but in the current crisis situation, it can support an ecosystem stakeholders’ effort by leveraging several collaborations. Based on the Tunisian experience, this study illustrates how a crisis can spontaneously create these collaborations between the maker’s community, the users (public healthcare professionals) and key stakeholders (universities, civil society and the private sector among others). To investigate this research question, we adopted a qualitative approach based on a single embedded case study and collected data through participant observation technique. The case study describes a process of crisis-driven innovation based on 3D printing technologies in order to provide personal protective equipment (PPE) to healthcare professionals. It highlights two distinct phases describing the evolution from a local collaborative model to the creation of a national ecosystem able to design, manufacture and address the growing need of the public healthcare system. Our findings show with empirical evidence the crucial roles played by the makers’ community, FabLabs and engineers in the fight against the COVID-19 pandemic. This study draws lessons on how a large health crisis can trigger national crisis-driven innovation (CDI) initiatives, which helped structure the makers’ network and promote collaboration towards a common national goal. A collaborative framework for CDI initiated by the Tunisian makers’ community is proposed in this study and could be adopted in similar crisis contexts, in Global South and North settings.
1. Introduction

Crisis usually fosters the conditions for new thinking and allows actors to innovate more freely and get out of their comfort zone. Crisis triggers are a new way of innovation because normal pathways are no longer accessible, which leads to improvising solutions in novel configurations of what is available (Tidd and Bessant, 2014). There is an urgent need to implement reliable communication to share knowledge and act as a part of a broader innovative network. It could be the best way to overcome a changing and dangerous period, where human and financial resources are limited (Chesbrough, 2003). This openness can take several forms, implying interactions between different knowledge and competencies holders. Interactions should occur with users as they are no longer considered as passive adopters of innovation, but rather as developers of innovation solutions (Van de Vrande et al., 2009). Marzouki and Belkahla (2020) have demonstrated that ‘lead users’, which is defined as the ability of users of ‘being ahead of the market’ and ‘having high benefits from innovation’ (Hau and Kang, 2016), has a positive impact on innovation success. This impact is intensified by knowledge sharing as users exchange their skills and competencies with other members of the community to develop innovative ideas, products, services or processes.

Involving makers as well as new innovation stakeholders in open innovation processes is even more topical in the context of a health crisis, such as the COVID-19 pandemic. Using well-established innovation models during a pandemic situation, especially in a developing country of the Global South, is challenged by the lack of medical equipment in addition to the multiple constraints imposed by the lockdown. Providing solutions in such health emergency situations requires new models of co-creation and intensive knowledge collaborations. Those solutions require a high level of synergy among key stakeholders, such as healthcare practitioners, makers, researchers and funding organisations. They also rely on extensive use of digital solutions for knowledge management, communication and manufacturing (Dougherty, 2012; Hatch, 2014). As everywhere in the world, Tunisia has been confronted with a shortage of medical equipment. Before the pandemic, policymakers in the Tunisian medical community were already talking about the need to produce medical equipment locally, but this health crisis has required practical and urgent actions taken by the government and official institutions, and by individuals and civil society organisations as well.

This study sheds light on the role played by the makers’ community during this pandemic in the Tunisian context. Since the beginning of the outbreak, makers, engineering schools, hospitals, medical staff and several key stakeholders (civil society, NGOs, private sector, etc.) have joined forces to find responsive and innovative solutions to help the Tunisian healthcare system. A number of initiatives have sprouted up in various regions of Tunisia, resulting in the development of multiple innovations in several applications at varying levels of maturity (idea, prototype, proof of concept, finalised innovation). These innovations had two main similarities: they relied on the extensive use of digital fabrication technologies, and they followed the principle of open-source hardware (OSH), as described by Ackermann (2009). Some researchers consider that maker communities and OSH movements are mainly located around FabLabs and maker spaces, unlike their open-source software (OSS) counterpart, whose development is promoted in the virtual world (Hausberg and Spaeth, 2020). This study shows that, during a crisis, initiatives can emerge in the virtual world and ultimately give rise to coordinated actions on the ground to face the crisis.

Therefore, the main purpose of this study is to propose a process model of crisis-driven collaborative innovation based on 3D printing technology. Our research aims to present a concrete example of the key role played by the makers’ community in supporting the Tunisian healthcare system in the fight against COVID-19, through open-source innovations. It illustrates how a crisis can create spontaneously a need for innovation and open up opportunities for ecosystem stakeholders to collaborate in a new way. The outcome of this study is rich in lessons relevant for the countries of the Global South and could just be as useful for the Global North, as the crisis has had worldwide consequences. In our study, we set out to answer the following research questions:

RQ1: How does the COVID-19 health crisis trigger new innovation processes and practices in the case of a country in the Global South?

RQ2: To what extent could the maker movement shape the innovation ecosystem in response to a health crisis in a resource-constrained environment?

This article is organised into five sections. After the introduction, Section 2 reviews the literature on health crisis-driven innovation and the role of the maker movement in innovation activities. Section 3 describes the methodology adopted to respond to our research questions. The findings of our study are presented in Section 4 and are discussed in the last section.
2. Theoretical background

2.1. Crisis-driven innovation (CDI) during a health pandemic

It has been 18 years since the open innovation paradigm was developed by Chesbrough (2003). While its scope of adoption in several fields is becoming wider, the current COVID-19 crisis seems to give the latecomers the opportunity or maybe the obligation to review their innovation strategy by focusing on more collaborative business models. Seeger et al. (1998) define a crisis as a ‘specific, unexpected and non-routine event or series of events that create high levels of uncertainty and threat’ (p. 233). The seriousness of the situation is such that the result of the crisis brings drastic changes. In fact, the COVID-19 crisis could be considered as an external event that triggers the disruption and pushes entrepreneurs who have a sense of alertness to seek new opportunities. Following the Schumpeterian concept of ‘creative destruction’, a crisis provides opportunities that can materialise by reorganising and up-skilling R&D activities (Cincera et al., 2012).

Innovating during a health crisis requires taking into account several constraints, rethinking the process configuration and adopting creative working methods (Bessant et al., 2012). It also disrupts traditional innovation processes, by bringing together actors with different profiles and creating conditions favourable to the emergence of new trajectories (ibid). Basically, disruption is defined as a process whereby a smaller company with fewer resources can successfully challenge established incumbent businesses (Christensen et al., 2015). Bessant et al. (2012) have identified five steps to go through in the situation of crisis-driven social innovations: crisis, observatory, laboratory, prototyping and scaling and diffusion. The process is triggered when a context of crisis or extreme condition occurs. Consequently, the observation stage entails carrying out research activities in order to come up with innovative solutions to deal with the crisis. The laboratory stage makes it possible to conduct experimentation around core ideas, and proceed to the prototyping stage in order to bring to life new innovations and test them. Finally, the last stage focuses on scaling and diffusion, which means standardising and replicating the core model to ensure the adoption and spread of innovations.

Disruptive innovations present opportunities for countries in the Global South in terms of industry structures, and have often given rise to social changes (Fox, 2014; Seo-Zindy and Heeks, 2017). The social exchange theory (SET), which refers to the extent of any social form of exchange, including tangible/intangible and material/non-material goods, exchanged between individuals/organisations, stipulates that abrupt crisis, such as the COVID-19 outbreak, often requires new and untested behaviour under time constraints, which makes the ability to assemble the necessary resources immediately critical (Mora Cortez and Johnston, 2020). In the same line, Preikschas et al. (2014) argue that fighting against a crisis by combining the resources of different companies in industrial relationships enables partners to achieve goals that could not otherwise be achieved alone, making possible value co-creation via reciprocal and mutually beneficial ties. Therefore, in crisis times, collaboration and social exchange can foster knowledge transfer, and shape innovation and R&D activities.

2.2. The maker movement role in innovation activities

FabLabs and the maker movement in general have brought significant socioeconomic and organisational changes based on several concepts such as the sharing economy, crowdfunding, open innovation and end-user entrepreneurship (Browder et al., 2019). 3D printing and FabLabs-used technologies have been considered among the most promising and challenging technological developments in recent years; thanks to affordable access to digital fabrication tools (Gershenfeld, 2007 in Browder et al., 2019). They have allowed mass customisation on a very large scale and created significant opportunities for co-creation between firms and their customers (Rayna et al., 2015). Raasch et al. (2009) have highlighted the interdependence and collaboration of communities of individual developers belonging to the maker movement and profit-oriented corporate entities within open design and production environments. According to Hausberg and Spaeth (2020), the creation and development of OSH for scientific uses and the progress of 3D printers are the two main reasons which contributed to the success of the maker movement. Despite this development, little is known about the role played by makers in open innovation and R&D activities, and on how they share intensive knowledge for innovation. Studies on the maker community agree that there is an interest in social and environmental issues in both the Global North and the Global South. However, some studies show a specific interest in the Global South in urgent and more local issues (Seo-Zindy and Heeks, 2017). Regardless of the purpose, the resulting products are generally a major source of product improvements, as well as totally new products, in established industries.
3. Methodology

To investigate our research questions, we adopted a qualitative approach based on a single embedded case study. For Yin (2009), the use of case study methodology is particularly useful in situations where we want to shed light on the ‘how’? and ‘why’? of a contemporary set of events. Indeed, it allows investigating ‘a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident’ (p. 18). They are also appropriate for learning from rarely occurring events, which is the case in this research. More particularly, the current research focuses on the role of the maker movement in the development of innovative solutions to support the Tunisian public healthcare system during the COVID-19 outbreak. Our research design followed the guidelines proposed by Yin (2009) to ensure construct validity and reliability in planning and executing a case study.

Data were collected from a variety of sources and took place between mid-March and April 2020. First, we used participant observations mode as one of the authors took an active part in the innovation process. The three other authors played non-participant observers’ roles to bring objectivity to the study and reduce bias. The use of this technique in a single case study provides valuable information and a deeper understanding of organisational practices and the innovation process. It helps in drawing solid scientific conclusions (Yin, 2009; Reischauer, 2015). For the purposes of the study, two phases of observations were conducted. In the first phase, we observed the activities of FabLab ENIT, which created a virtual 3D printing network in the Tunisian capital to provide medical equipment to support the public healthcare system. FabLab ENIT is the first FabLab created in Tunisia, and it is hosted at The National Engineering School of Tunis (ENIT), one of the largest engineering schools in the country (Ben Rejeb and Roussel, 2018). The second phase of observation started when the makers of FabLab ENIT joined their efforts with other makers and stakeholders from different fields (academia, healthcare, private sector, civil society, etc.) to form a national network (in the form of a collective). During this second phase, the observations focused on the activities and the interactions within the collective. In order to properly document this Tunisian experience and respect the chronological order of events, the participant observer took daily handwritten field notes (assembled in the form of a diary) in a notebook. Notes were regularly synthesised and discussed with the co-authors.

Second, as shown in Table 1, participant observation was complemented by the recording and the analysis of four other sources, namely, digital online database, social media posts, formal and informal exchanges and official meetings. Due to the confinement measures, the exchanges between the members of the initiative were mainly carried out via social media and online meeting applications. The widespread use of digital technologies facilitates data collection (Ritala et al., 2020) and makes data analysis more relevant (Antons et al., 2020). To ensure the high quality of the study, the data collection process was carefully documented, and all data were recorded. We performed content analysis for collected data interpretation, and regularly, went back and forth between the literature review and the case study material. Field observations, meetings and chat conversations were analysed taking into consideration three elements: time, steps of the CDI’s model (Bessant et al., 2012) and the different players involved in the process. The research questions guided our focus in the coding process. We especially looked out for the main steps and the key success factors of CDI during the COVID-19 outbreak.
4. Findings

The results show that in the case of Tunisia, FabLabs, makers and engineers played a crucial role in the fight against COVID-19. In less than a month, they were able to develop innovative solutions and create around them an ecosystem of open and social innovation. During the COVID-19 crisis, field observations revealed the existence of two distinct phases, albeit close to each other chronologically. They are modelled in the following subsections. The initial phase represents the first initiatives and R&D activities that were done spontaneously in a fragmented way, adopting a local collaborative model (geographically concentrated). In a second phase, there was a grouping of initiatives (in the form of a collective), and the makers could, therefore, benefit from the support of various stakeholders. This led to the creation of a national ecosystem able to develop and offer equipment for public hospitals. The chronology of actions carried out in the context of the community of Tunisian makers followed a process similar to that proposed by Bessant et al. (2012) describing the process of innovation during times of crisis.

4.1. Initial phase: local collaborative innovation model to fight COVID-19

This phase began around mid-March 2020. FabLab ENIT was directly contacted by doctors working in a public hospital in Tunis, asking for protective face shields. According to our observations, in just 2 days, FabLab ENIT makers were able to design and manufacture a 3D-printed face shield mask based on several open-source prototypes. After rigorous testing and multiple feedbacks, the final prototype was approved by the medical staff (the design is licensed under a Creative Commons Attribution Non-commercial 4.0 International license). After the product specifications phase, the design and production process started. In our case, the COVID-19 outbreak forced university professors and makers to consider some constraints such as time, people safety, confinement decisions and reduced number of 3D printing machines and the manufacturing material associated. Therefore, virtual 3D printing network was created to work and produce in a more efficient way and ensure the safety of the makers. This network was coordinated by a university professor from ENIT (the active observer of this study) and two engineering students.

To quickly start the production and distribution of the protective face shield masks to the hospitals, the FabLab machines were distributed to some makers so they can work from home. Regarding the supply of printing filaments, a small (informal) fundraising allowed the network to have the required material to start the production. At the same time, an information system in the form of a dynamic and shared database was created to plan and coordinate the production and distribution logistics in real time. It was used as a supply management platform, allowing great flexibility in balancing the 3D printing capacities with the healthcare practitioners needs.

With the success of the first batch tested by the medical unit and thanks to a positive word-of-mouth effect, further orders followed from various hospitals. To manage the distribution process, FabLab ENIT, in collaboration with the Faculty of Medicine of Tunis, identified one or two points of contact (POC) at different hospitals of the capital. Moreover, we observed that communication represented a key success factor for the initiative of FabLab ENIT and its network. Their communication strategy focused on two main elements, namely documentation and dissemination (the makers documented all the details of the prototype and uploaded the documentation on websites hosting open-source projects such as, Github) and Social Media communication (they used Facebook and LinkedIn platforms to make call-to-actions and communicate about the achievements of the network). This strategy was successful at different levels.
Firstly, it allowed the network to grow because other networks and makers across the country contacted FabLab ENIT looking for collaboration. Secondly, it allowed other makers around the world to replicate the model and help their respective countries in the fight against COVID-19. Finally, it attracted the attention of donors, civil society actors and suppliers who wanted to support the initiative. At this point, we started noticing the beginning of the development of a national ecosystem which will be described in more details in the next section. Simultaneously, the success of the communication strategy generated an increasing demand from hospitals from the capital and other regions of the country, which required looking for new sources of funding. This led FabLab ENIT makers to use a Tunisian online crowdfunding associative platform to collect donations.

In summary, this initial phase captures the first wave of responses of Tunisian makers to the calls made by hospitals and medical staff. In just 10 days, 1,000 face shield masks were produced, and offered to 29 public healthcare structures. To schematise the key steps of the process that enabled these achievements, we relied on the CDI model developed by Bessant et al. (2012). Figure 1 represents the CDI model adapted to the case of FabLab ENIT experience, and shows that the main stages of the process took less than 1 week to be performed. This process may seem at first glance linear and straightforward. This is explained by the very short delay of its implementation due to the situation of emergency. However, retroactive and informal loops and feedback were observed between the different stages, which remind us of the chain-linked model proposed by Kline and Rosenberg (1986). This model recognises a number of complexities in the innovation process, including the numerous feedback loops between the various sequential stages as new knowledge is captured during the progress in the innovation process. Moreover, in the case at hand, the process did not stop at the ‘Scaling and diffusion’ phase as suggested by Bessant et al. (2012), but it evolved into an open innovation ecosystem with a national scope. This evolution will be presented in the following section of the article.

4.2. Second phase: national collaborative crisis-innovation ecosystem

In addition to FabLab ENIT network, similar initiatives, with other business models (e.g. physical networks operating in engineering schools), were simultaneously organised in other areas of the country. The increase in demand for protective face shields prompted the various networks to join forces to engage in new collaborations with a wider scope, that is, at a national level. The first exchanges and contacts were made informally through phone calls and social media. Subsequently, messenger groups were created to better communicate and collaborate, in addition to video conferencing apps. This is how the collective ‘Yes We Breathe’ was born. It brought together national initiatives from a broad range of sectors from different parts of the country (including universities, FabLabs, NGO’s, national and foreign companies, healthcare organisations, etc.), to provide

Figure 1. Process model of crisis-driven collaborative innovation based on 3D printing technology (adapted from Bessant et al., 2012). [Colour figure can be viewed at wileyonlinelibrary.com]
financial and logistical support to the supply chain. Figure 2 shows the main stakeholders involved in this innovation ecosystem. All these stakeholders shared the common vision for supporting the Tunisian healthcare system in the fight against COVID-19.

Our results show that, since its constitution, the collective had to face two main challenges: first, the sharp increase in protective face shields orders; and second, the shortages in key manufacturing materials (mainly 3D printing filaments). Thus, while using 3D printing was the most practical and simplest option to start immediate production of the face shields, the collective decided to respond to the huge and urgent demand by migrating to faster technologies, such as laser cutting and plastic injection moulding, to scale up the production. Plastic injection technologies are often used in industry because they are more flexible and efficient than 3D printing processes. To speed up the production of the face shield masks, the collective decided to team up with local manufacturing companies to produce them for free using a plastic injection process.

To organise the supply chain in all Tunisian territory, the online database developed by FabLab ENIT was adopted by the collective in order to track the supply of raw material and the distribution of the masks. The 3D printers were directed towards the research and development of other prototypes validated by doctors and healthcare facilities, such as single ventilators and respiratory valves, disposable uniforms and gloveboxes. Moreover, the collective teamed up with the Tunisian–Italian chamber of commerce, to produce 3D-printed valves designed by an Italian company. These valves could turn a snorkelling mask into a ventilator mask. The prototypes were available on the company’s website (https://www.isinnova.it/easy-covid19-eng/), and were free for use. This partnership with manufacturers represented a new shift in the innovation process, as we observed that the collective started to have an economic impact, in addition to the social impact of its initiatives. Indeed, the transfer of these products to the private sector offered the Tunisian manufacturers supporting the collective the opportunity to sell the masks to private health structures and export them to foreign markets. This positive economic impact also applied to the start-ups involved in the ecosystem, which played a very active role in the various actions run by the collective. This enabled them to improve their reputation, to develop new products and to grow their networks. It is also worth noting that the collective had been mentoring and encouraging the makers and engineers, who were at the heart of the R&D activities, to capitalise on their experience by participating in innovation competitions and creating their own start-ups. Our findings show that all in all, the members of the collective ‘Yes We Breathe’ developed nine prototype models of 3D-printed face shield masks. In less than a month, over 100,000 masks were freely distributed in the country. Among other achievements, the collective delivered 600 modified snorkelling masks, 1,600 valves and 500 respirator splitters to the Ministry of Health, and produced a respirator for a public hospital.

Figure 2. Makers’ community ecosystem under COVID-19 crisis. Source: Developed by authors. [Colour figure can be viewed at wileyonlinelibrary.com]
Finally, the content analysis of the different conversations and exchanges that took place during the two phases of observation revealed that four common themes emerged from the discussions, namely ‘Supply chain management’, ‘R&D’, ‘Funding’ and ‘Communication & Networking’. In the second phase, the discussions contained a richer flow of information with regard to the previous phase and a new theme was detected: ‘Production’. This is understandable as in this phase we witnessed the creation of the collective, the partnership with the local manufacturers and the scaling up of the production. The major themes and sub-themes identified within the two observation phases are described in Table 2.

### 5. Concluding discussion

This article focuses on the role of the maker movement’s ecosystem and 3D printing technologies in managing a health crisis situation, such as COVID-19 outbreak, particularly in a country from the Global South. Crisis requires opening up the process to some unconventional players because they have motivations and skills which are not required in normal times. The use of participant observation techniques offered a unique opportunity to witness first hand and participate in the collaborative experience between public healthcare professionals, makers and key stakeholders. Through an iterative process, this kind of technique has allowed us to gather detailed data and identify emerging themes to answer our research questions.

First, our results show that the experience of the Tunisian makers during the COVID-19 outbreak is in line with the four main building blocks identified by Giusti et al. (2020) in the classification framework for open innovation in healthcare ecosystems: healthcare ecosystems’ stakeholders (traditional and new such as makers and FabLabs); knowledge transfer among them during the exploration and exploitation stages of innovation development (sketches, 3D models, prototypes and mass production); players’ motivations for innovation (crisis answers and open source) and players’ position in the innovation process (upstream, local and regional). From this experience, we came up with a two-phase process model of crisis-driven collaborative innovation based on 3D printing technology as well as a general framework of a CDI ecosystem. In the first phase, the initiatives were fragmented and centred at the local level (city or region). In just a few days, different networks decided to join efforts to evolve, in a second phase, into an ecosystem with national scope, supported by different stakeholders. These findings answer our first research question (RQ1) on how a health crisis can trigger new innovation processes and practices in the case of a country in the Global South.

The key stages of the innovation process observed during these two phases are summarised in Figure 3. It shows the temporal dynamics of the constitution of the stakeholders’ network, and how fast fragmented initiatives and networks would reorganise themselves to a more collaborative and structured national ecosystem providing a rapid response to the COVID-19 crisis. This result widens the field of application of open innovation, usually reserved for situations characterised by high technology intensity, the emergence of new business models, the development of new knowledge and the need to support internal R&D activities (Huizingh, 2011; West and Bogers, 2014; Giusti et al., 2020). This multi-actor innovation process fostered co-creation to provide protective equipment to the Tunisian healthcare system. Our results confirm the fact that innovation is necessarily a multi-party activity (Tidd and Bessant, 2014); especially for a Global South country where healthcare should be ‘available’ and ‘accessible’ to every citizen of the country on a sustainable basis (Mazumdar-Shaw, 2018). The involvement of doctors and healthcare professionals in this innovation process corresponds to the case of ‘user-linked innovation’, in which user’s ideas provide prototypes which are then taken up and improved upon for widespread diffusion (Von Hippel, 1986). This could impose...
disruption and stimulate people’s creativity and ingenuity to end up with new forms of innovation involving new kinds of resources, governance, and delivery (Davies and Boelman, 2016) even in low technology intensity contexts. This is particularly true for the case of Tunisia, which is one of the economies that stands out because it harbours significant innovation potential as it has higher expenditure on education, is open to technology adoption and inward knowledge flows, has an improving research base, and is characterised by active use of information and communication technologies (ICTs), as well as a stronger use of their IP systems (Dutta et al., 2020). These strengths of the national innovation system could have contributed to creating crisis-driven processes to face the challenges of COVID-19 pandemic.

Second, our study shows that the maker movement in a Global South country can shape the innovation ecosystem in response to a health crisis (RQ2). This reaffirms the dynamic nature of this young community in Tunisia and its important role in addressing local issues (Ben Rejeb and Roussel, 2018; Oladele-Emmanuel et al., 2018; Abbassi et al., 2020). On the one hand, this confirms the findings by Corsini et al. (2021), who analysed the responses of makers to COVID-19 through the lens of frugal innovation. On the other hand, it can be noted that digital transformation opens up new opportunities for Global South to access new production techniques and new markets (Ciuriak and Ptashkina, 2019). The use of ‘fast-emerging technologies’ such as 3D printing, as defined by Shahrubudin et al. (2019), in the fight against COVID-19, is a big opportunity to foster innovation in Global South countries because they could be implemented, developed and maintained without external assistance. In addition, they could realise exponential social and economic changes. In our case, the collaborative innovation model adopted by the Tunisian collective shares the main characteristics of what Christensen et al. (2006) call ‘Catalytic innovations’, which are a subset of disruptive innovations, distinguished by their primary focus on social change, often on a national scale. Our results illustrate that the Tunisian makers and the ecosystem they triggered created a systemic social change through scaling and replication of the nine models of 3D-printed face shield masks. To raise more monetary resources of this innovation project, new sources of funding, such as crowdfunding, were mobilised. In the end, healthcare structures’ needs were fulfilled in emergency circumstances and during lockdown with simple and affordable innovations. Moreover, our model shows the intensity and speed of the collaborative work implemented by the makers during this crisis. The main motivation for this collaboration was driven by the emergency to address a vital health crisis. This is in line with the results of Bessant et al. (2012) for innovation in times of crisis but contrasts with some other findings about the motivation of the maker community in general such as enjoyment-based intrinsic motivation (Hausberg and Špaeth, 2020), or a form of creative self-expression (Atakan et al., 2014). Interestingly, this momentum of good initiatives during this crisis is very similar to (and
perhaps rooted in) the surge that Tunisia experienced in the aftermath of the youth uprising during the Tunisian Revolution in 2011.

Third, based on the analysis of the discussion flows that took place during the observation phases, we argue that CDI processes under a health outbreak, such as COVID-19 can be driven by a set of key success factors (KSF). More specifically, we identified five KSFs, namely ‘Supply chain Management’, ‘R&D’, ‘Production’, ‘Funding’ and ‘Communication & Networking’. This set of innovation KSFs, which can be applied in the Global North as well as in the Global South, is consistent with the results of previous frameworks that have studied best practices for innovation (e.g. Adams et al., 2006; Nelson et al., 2014). The emergence of the ‘Production’ factor in the second phase could be explained by the interest of all partners in moving towards an industrialisation stage in order to meet the growing needs of the health sector all over the country. The presence of the ‘Communication & Networking’ factor in both phases indicates the importance of implementing reliable communication to share knowledge and act as a part of a border innovative network. This is in line with what has been described by Bessant et al. (2012) that, under extreme conditions, ‘there is an urgent need to establish robust and reliable communication networks. Gathering information, processing it and making it available to those who need it to shape decisions about resource allocation, prioritising logistics and real-time status reporting are all key needs towards which innovation is targeted’ (p. 231).

The case of Tunisia is evidence of the role played by digital and communication technologies and social media in supporting innovation activities during COVID-19 pandemic. These technologies represent a pillar for succeeding in crisis management and in promoting the dissemination of general information or events, and technical information (Mora Cortez and Johnston, 2020).

To sum up, our research sheds light on a relatively unexplored research field which is revisiting the involvement of makers and digital technologies in innovation activities when a Global South country is facing health crisis circumstances. Overall, our theoretical contribution is twofold: first, it combines various streams of literature (e.g. CDI theory, open innovation theory, R&D literature and the maker movement literature) in order to add value to the innovation literature. By aligning these theories, we shed light on the crucial role of open innovation in fighting COVID-19 pandemic, from a Global South perspective. We believe that R&D activities and innovation performance in crisis times can be fostered by the capabilities of the makers in acquiring, assimilating and exploiting knowledge from all the ecosystem’s partners, for technology transfer purposes. Second, our research expands and contributes to a better understanding of the CDI model of Bessant et al. (2012), by showing that, during a health crisis, the innovation process is not linear: retroactive and informal loops are necessary between the different stages of the process. Our research also illustrates how the innovation process oversteps the ‘Scaling and diffusion’ phase by evolving into an open innovation ecosystem with a national scope.

From a methodological perspective, the use of participant observation supplemented with the monitoring of social media and virtual meetings and conversations represents an important contribution to innovation management research. In doing so, this study responds to the call from Ritala et al. (2020) for greater methodological diversity in this field, both in terms of design and data collection. From a practical perspective, this research has key implications for policy makers and various stakeholders. Indeed, it provides insights about makers’ network-related innovations by underlying mechanisms between three innovation dimensions: social exchange, knowledge creation and sharing, and technology resources and entrepreneurship outcomes. On the entrepreneurial level, under normal circumstances, some of the ideas proposed by the makers would not be considered attractive businesses, but when facing extreme conditions, the makers’ community found support from stakeholders who could make their business model profitable with new contractual terms between private (industrials and start-ups) and public (makers, academia and healthcare structures) sectors. This positive economic impact also applied to the start-ups involved in the ecosystem. Considered as the main source of innovation (Wang et al., 2016), these start-ups played a very active role in the CDI process conducted by the collective.

This research is, of course, subject to some limitations. For instance, our research was based mainly on observations. To enrich this case study, it is necessary to conduct semi-structured interviews with key players from across the innovation ecosystem (makers, engineers, medical staff, professors, entrepreneurs, suppliers, etc.). This will complete the analysis made in this research by integrating other perspectives and could lead to the development of a business model for the use of 3D technologies and makers in response to a health crisis. In addition, our research is based on a single case study conducted in Tunisia, a country that is classified under the lower middle-income economies, but with a significant innovation potential and good access to ICTs. Future studies involving less innovative and digitised countries.
from the Global South might provide deeper insights and different KSFs to sustain CDI. Additionally, the use of multiple case studies will give us a more holistic view about the maker movement contribution to foster innovation in crisis time. Further research can also explore the role of open-source innovation and the maker movement in fighting other kinds of crisis such as environmental or social crisis.

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