Maker Networks Fighting Covid-19: Design Guidelines for Redistributed Manufacturing (RDM) Models

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ABSTRACT

Maker Networks indicate how society organizes itself to overcome significant challenges, such as the lack of Personal Protective Equipment (PPE) observed during the COVID-19 pandemic. We analyze initiatives that produced PPE for frontline health staff to propose design guidelines for implementing *RDM-Maker Networks*: networks of people and organizations in the Maker Movement that collaboratively produce goods or services organized in a redistributed manufacturing (RDM) model. This paper has two main results: five Maker Networks in Brazil analyzed in terms of their RDM features and the subsequent design guidelines. We selected cases through several criteria like their location and the type of one of their nodes. Those criteria also represent limitations that further works can address.

Keywords: Maker Movement, Maker Networks, Redistributed Manufacturing, Design Guidelines.

INTRODUCTION

Recent works on Maker Movement have claimed its influence on economic development and innovative solutions generation (Chen & Wu, 2017). There is literature on how makers are organized or inserted in some network (Giusti, Alberti, & Belfanti, 2020; Hamalainen & Karjalainen, 2017; Johns & Hall, 2020; Smith, 2017). There is also literature on positive outcomes of their collaboration (Lindtner, 2015; Roedl, Bardzell, & Bardzell, 2015). However, few have explored a networked production model when it is deeply related to the Maker Movement.

In literature, there are works associating makers to production dynamics like peer production (Kohtala & Bosqué, 2014; Menichinelli, Bianchini, Carosi, & Maffei, 2017; Wolf & Troxler, 2016; Wolf, Troxler, Kocher, Harboe, & Gaudenz, 2014) and social manufacturing (Hamalainen & Karjalainen, 2017; Hirscher, Mazzarella, & Fuad-Luke, 2019; Yang & Jiang, 2019). However, it has not yet described the production model of cases where a network of people and organizations inserted in the Maker Movement are collaboratively producing some good or delivering some service in the context of redistributed manufacturing.

This article describes design guidelines based on the analysis of five Maker Movement initiatives located at Brazil Southeast and how they organized themselves to produce PPE like Face Shields, a piece of vital equipment for the frontline healthcare personnel facing COVID-19.

Universities' laboratories and departments played an essential role in many initiatives, especially those owning fast prototyping technology like 3D-Printing (3DP) and cutting-based machines ("cutter," henceforth), like cutting plotters, die-cutting, laser cutters, and vinyl cutters. The present authors are members of the Design for Social Innovation and Sustainability Network (DESIS Network) Laboratory in Rio de Janeiro (Rio DESIS Lab, 2020), which became a productive node of the SOS 3D COVID19 network, one of the cases analyzed here. We got in touch with several actors involved in this process, and comparing with the theoretical framework explored in the study, our initiative seemed to represent an implementation of RDM. Then, we started to observe similar collaborative networks (Manzini, 2012), which became a good set of cases to study.

1. THEORETICAL FRAMEWORK

1.1. Maker Movement and Maker Networks

Maker Movement may be considered the practical side of Maker Culture (Peppler & Bender, 2013). Maker Culture is focused "on using and learning practical skills and then applying them creatively to different situations" (Niemeyer & Gerber, 2015, p. 218), having a more general and philosophical meaning (Nascimento & Pólvora, 2016; Von Busch, 2012). Maker Movement comprises "a community of hobbyists, tinkerers, engineers, hackers, and artists who creatively design and build projects for both playful and useful ends" (Martin, 2015, p. 30), which represents a more objective view of the phenomenon (Halverson & Sheridan, 2014; Peppler & Bender, 2013).

Any group of people in the Maker Movement can be organized in some kind of network. When considering their action in society and the organizations they may be related to, the concept that comprises this structure is the one of a Maker Network, i.e., a network that enables the "usefulness of open and distributed production design models not as alternative systems to the world of industry and services but as complementary systems to them." (Menichinelli, Bianchini, & Maffei, 2020, p. 3).

A Maker Network may bring many benefits either to urban areas (Wolf-Powers et al., 2017) or rural ones (Smith, 2017) and may generate impacts on how actors interact (Browder, Aldrich, & Bradley, 2019; Doussard, Schrock, Wolf-Powers, Eisenburger, & Marotta, 2017); the technology usage (Waller & Fawcett, 2014; Wolf-Powers et al., 2017); the product/service characteristics (Browder et al., 2019; Hamalainen, Mohajeri, & Nyberg, 2018); and the development of business models (Doussard et al., 2017; Santos, Murmura, & Bravi, 2018; Smith, 2017).

This paper defines a Maker Network as a group of people and organizations related to the Maker Movement working as a team to produce some good or deliver some service. What connects these actors to the Maker Movement are the tools used, the type of products or services, their relation to the places of production and consumption, how they interact, and the operational model of their collective work.

A node composing a Maker Network may be a person, a university (or a department), a research institution (or a laboratory), a subnetwork of makers, a makerspace, an organization such as a small company or a non-governmental organization, or even a big company (or a division). Interconnections between nodes are similar to descriptions found in the literature. For instance, 'digital maker networks' has been used to describe "a series of

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'pop up' manufacturing nodes or 'maker centres' [that] were set up to explore the idea of local manufacturing bases connected to a wider network of supporting manufactures" (Smith, 2017, p. S2661). See also Menichinelli (2020), where the author explores several frameworks for the interplay of the actors involved in this process under the proposal of the "Maker City" (Menichinelli, 2020, p. 97).

1.2. Redistributed Manufacturing (RDM)

The earliest RDM definition concerns the influence of technology and business model on the production location and scale (Ford & Minshall, 2015; Pearson, Noble, & Hawkins, 2013). Further works consider environmental aspects and contributions for Circular Economy and Resiliency (Freeman, McMahon, & Godfrey, 2016; Prendeville, Hartung, Purvis, Brass, & Hall, 2016).

In this work, we use the same RDM definition from Srai and Kumar et al. (2016), which works it from a literature review, making it a more precise definition than the umbrella concept (Hamalainen et al., 2018) of distributed manufacturing (or production):

> 'the ability to personalise product manufacturing at multiple scales and locations, be it at the point of consumption, sale, or within production sites that exploit local resources, exemplified by enhanced user participation across product design, fabrication and supply, and typically enabled by digitalisation and new production technologies'. (pp. 6932-6933).

Other RDM characteristics found in literature reside mainly in the application of Industry 4.0 technologies (Turner et al., 2019) and the move from a centralized mass scale towards a small-scale localized production (Chandima Ratnayake, 2019; Freeman, McMahon, & Godfrey, 2017; Prendeville et al., 2016; Srai, Harrington, & Tiwari, 2016; Veldhuis et al., 2019).

Hennelly, Srai, Graham, Meriton, & Kumar (2019) developed a framework to describe the features required by RDM implementations. Their analysis, applied to makerspaces, can be applied to identify existing or lacking RDM features on the Maker Networks under investigation in this study and is used as an initial reference to define RDM implementation guidelines.

Figure 1 represents this RDM framework. Each box contains a parameter for analyzing the cases.

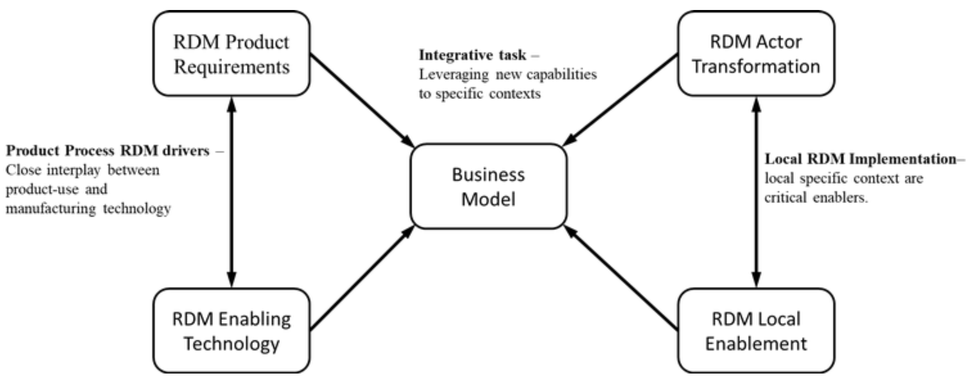

Figure 1: Integrated characteristics for implementing RDM (source: Hennelly et al. 2019).

The description of each parameter (Hennelly, Srai, Graham, Meriton, & Kumar, 2019) follows below.

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Product requirements. "RDM requires the manufacturing of products in which the customer is much more involved and participative in their development." (p.542)

Enabling technologies. "Rapid advances in digital design and fabrication technologies are creating radical new possibilities for innovations in production and consumption." (p.542)

Actor transformation. "(...) requires a transformative culture change in existing supply chain governance." (p. 543)

Local enablement. "(...) localization means far less need for costly international supply chains, low-energy use and carbon footprint, and more reliance on domestic materials that come from recycling processes or are grown or produced in the community." (p.543)

Business model. "The different business models link the unique contexts and enablers for a given sector and/or region for effective implementation." (p.543)

2. METHODS

2.1. Literature review

The review used Scopus and Web of Science as indexed bases and Google Scholar for a more general search. The study relies on literature from two searches: one focusing on Maker Movement and the other dealing with RDM. In both cases, the tool used to eliminate duplicates, and select papers by title, abstract, and keyword inspection, was Excel™ spreadsheets. Table 1 presents the process.

Table 1: Selection of papers for the literature review.

Scopus + Web of Science	**Subject**	
	Redistributed Manufacturing	**Maker Culture/Maker Movement**
Search sentence	"redist* manuf*" OR "manuf* redist*" OR "redist* of the manuf*" OR "manuf* proc* redist*" OR "re-dist* manuf*" OR "manuf* re-dist*" OR "re-dist* of the manuf*" OR "manuf* proc* re-dist*"	"maker movement" OR "maker culture" OR "DIY culture" OR "DIY movement" OR "do-it-yourself culture" OR "do-it-yourself movement" OR "do it yourself culture" OR "do it yourself movement"
Results	Scopus: 18 / Web of Science: 31.	Scopus: 307 / Web of Science: 417.
Duplicates	16.	210.
Inspection by Title, Abstract & Keywords	The remaining 33 papers.	("networks", "literature", "maker movement", "maker culture", "economic development", "entrepreneurship", "supply chain"): 21.
Google Scholar	Pearson et al., 2013.	Kohtala and Bosqué, 2014; Wolf et al., 2014; Wolf and Troxler, 2016; Menichinelli et al., 2017, Yang and Jiang, 2019, Manzini, 2012, Zhang, Tan, Sun, and Yang, 2020

2.2. Case study

This article relies on theoretical sampling to "extend emergent theory" (Eisenhardt, 1989, p. 537) and on case study (Yin, 2018). First, our theoretical sampling matched the theoretical propositions that made us envision the case study (Yin, 2018, p. 215). Then, we described how the cases implemented RDM by matching patterns (Yin, 2018, p. 223) from the literature on RDM, translated by the questions to be answered (Table 2).

2.3. Questions to analyze RDM-Maker Networks

Based on "Key RDM-makerspace characteristics" (Hennelly et al., 2019, p. 543), we formulated a series of questions, as seen in Table 2. Answers altogether indicate how a case implemented RDM.

Table 2: Questionnaire related to RDM implementation characteristics.

Dimension	Characteristic (question)
Product requirements	Proximity (Where were the equipment delivered?)
Product requirements	Customization (Had any modification been made to the model?)
Product requirements	Real-time (Time from prototype until the first batch?)
Product requirements	Innovation (Was any adaptation made on or with any tool or equipment?)
Product requirements	Environment/Circular economy [ECE1] (Had tool sharing been observed in any node?)
Product requirements	Environment/Circular economy [ECE2] (Have nodes themselves repaired any tool?)
Product requirements	Environment/Circular economy [ECE3] (Did the network use recyclable materials?)
Product requirements	Digital [1] (How the network got the files?)
Product requirements	Digital [2] (Who projected the files?)
Product requirements	User-participation (How did healthcare professionals contribute?)
Enabling technologies	Capacity (What was the daily output volume? [units/day])
Enabling technologies	Maturity (How were the machine operators skilled?)
Enabling technologies	Capability (Did the network exchange knowledge through digital media?)
Enabling technologies	3DP [Tools] (What were the tools used?)
Business model	RDM product design and materials [1] (What was the product's composition?)
Business model	RDM product design and materials [2] (What were the main manufacturing requirements?)
Business model	RDM cost model (How is it being financed?)
Business model	Commercialization (Were products sold, rent or donated?)
Business model	Product ownership/IP (Had files any cost?)
Business model	Alternative finance (Did the network use any alternative finance model?)
Actor transformation	Culture (Do nodes identify with maker culture/movement?)
Actor transformation	Leader (Are any members leading a project?)
Actor transformation	Education (Does any network actor provide a course?)
Actor transformation	Multidisciplinary (Are projects multidisciplinary?)
Actor transformation	Communication (How are PPE requests made?)
Local enablement	Institutional support (Did the network receive institutional support?)
Local enablement	Local networks (Do nodes integrate any local network?)
Local enablement	Social/Communities (Have any node contributed to a social project?)
Local enablement	Research (Does any node develop an R&D project?)
Local enablement	Students/Experts (Are there specialists in the network?)
Local enablement	Schools/Libraries/Labs (Network or any member contributes with some of these?)

2.4. Selecting cases

This study uses a qualitative approach to build design guidelines as an interpretative construction (Bryman, 2012). Although inside a reasonable range of cases to study (Eisenhardt, 1989), the number of cases selected was not supposed to explore all the possible configurations of Maker Networks allowed by definition, as presented in the theoretical section. Nevertheless, the selection of cases intended to include the same variety

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of nodes as described in the theoretical section: individuals, universities (or departments), companies (or divisions), research institutes, and makerspaces.

In this research process, there were several limiting conditions. We focused on the Brazilian region with the highest number of initiatives (Olabi, 2020), the Southeast, which happens to be the region with the highest number of cases of COVID-19 (Ministério da Saúde, 2020) as of the date of this research. Thus, where the action of the Maker Networks would be of most impact. Since the study began with a case – SOS 3D COVID-19 – with a university department as an essential node, we maintained the criterium of having at least one node located at a university. The exception was Rio Hacker Maker Space (RHMS): once a subnetwork integrating SOS 3D COVID-19, it became independent during the study. Other criteria were using fast prototyping technology and the initiatives donating the production output for public hospitals.

These criteria allowed us to select five initiatives, which had active websites and social networks with accessible information on how the PPE was being produced – which provided answers to Table 2 – except RHMS that required an interview.

2.5. Providing design guidelines

Once we identified how cases implement RDM, it was possible to grasp enabling operative principles, which, when linked to RDM characteristics derived from literature, form the design guidelines for RDM-Maker Networks proposed in this study.

The design guidelines are mostly based on the interpretation of the cases considering what they have in common and, if applicable, a particular case's specificities. Thus, it was possible to interpret the cases' information and generate the design guidelines by observing the findings.

The steps were the following: first, we described the cases according to the selection criteria, then, we explored the RDM features in tables (Table 3 and Table 5 to 8 – in the appendix). After that, the design guidelines were worked out. The evidence supporting them are found either in the cases' description and specificities or in the tables. Specific aspects observed in each case allowed to exemplify some guidelines. Table 4 summarizes the evidence observed for each design guideline.

3. FINDINGS

3.1. Maker networks: description

SOS 3D COVID19 (SOS). Located in Rio de Janeiro, we obtained information at SOS3DCOVID-19 (2020). Universities hosted two network nodes: The Federal University of Rio de Janeiro (UFRJ) and the Pontifical Catholic University of Rio de Janeiro (PUC-Rio). They produced Face Shields and Protective Goggles, and, besides university departments, individual makers were the network's primary members.

Rio Hacker Maker Space (RHMS). Located in Rio de Janeiro, we collected information at RHMS (2020). RHMS was related to the same university nodes as was SOS 3D COVID19: UFRJ and PUC-Rio. The network produced Face Shields and was composed of a group of professionals, students, and enthusiasts.

***Brasil Contra o Vírus* [Brazil Against the Virus] (BCV)**. Located in São Paulo metropolitan region, this Maker Network has a website (*BRASIL CONTRA O VIRUS*, 2020) where we first obtained their information. The Biofabrication Laboratory (Biofabris) located at the University of Campinas was the university-related node. The network produced Face Shields and Continuous Positive Air Pressure Non-Invasive Ventilators (CPAPNIV). The network included: universities' departments, research institutions, a shared workshop, and individual makers.

***Makers Contra a Covid-19* [Makers Against Covid-19] (MCC).** Located in São Paulo, we retrieved much of the information from their website (*Makers Contra a Covid-19*, 2020). University of São Paulo (USP) hosted the university-related node. They produced Face Shields, and the network included mainly individual makers.

***Trem Maker* [Maker Train] (TM).** Located in Belo Horizonte, this network has a website (*Trem Maker*, 2020) where we gathered the information about them. Federal University of Minas Gerais (UFMG) hosted the university-related node. This Maker Network produced Face Shields, and participants were mainly makerspaces and individual makers.

3.2. Analysis: RDM features

Table 3 contains the answers for an integrative group of characteristics for RDM implementation: the Business Model. As an integrative group, it incorporates other groups of characteristics. They are presented in the appendix as Tables 5 to 8, in the same order as in the theoretic framework section: Product requirements to Local enablement.

Table 2's questionnaire has many polar (yes-no) questions whose answers are sufficient to depict the cases as RDM implementations. However, in several cases, the initiatives had specificities. They are signed with an asterisk (*) at the correspondent answer. For each of the initiatives, we describe those specificities in session 3.3.

Table 3: Business model characteristics from cases.

Case	RDM product design and materials [1]	RDM product design and materials [2]	RDM cost model	Commercialization	Product ownership/IP	Alternative finance
RHMS	PLA, acetate, PVC, rubber band.	Comfort.	Own money and individuals' donations.	Donated.	No.	No.
SOS	ABS/PLA/PETG	3DP parameters, shield composition and thickness.	Institutional support and donations.	Donated.	No.	No.
BCV	Face Shield – 3DP: PETG/ABS/PLA/PET/PVC/PVA; Cutters: PET/PETG/PVC/PVA. CPAPNIV – Charlotte valve: PA12 (Nylon 12); Mask: see SUBEA .	Face Shield – The materials and the design, as oriented by physicians. CPAP NIV – Charlotte valve made with a process resulting in a porous-free product to avoid contamination.	Institutional support and donations.	Donated.	No.	Yes, crowdfunding, "*Vaquinha online*", see *Vakinha* .
MCC	ABS/PLA/PETG.	ANVISA - RDC Nº 356, see ANVISA .	Institutional support and donations.	Donated. *	No.	Yes, crowdfunding: "*Vaquinha online*", see *Vakinha* .
TM	ABS/PLA/PETG.	ANVISA - RDC Nº 356, see ANVISA .	Institutional support.	Mainly donated. TM also developed a model exclusive for selling while maintaining the donations for hospitals.	No.	No.

3.3. Cases Specificities

Rio Hacker Maker Space (RHMS). RHMS members reside in Rio de Janeiro, the same city as the hospitals they delivered the PPE to. A member designed a PVC pipe-based face shield model from scratch as an alternative to the 3D-printed model. The interviewee considers the Maker Movement related to open innovation processes. RHMS provided classes and organized dissemination activities in a public school in Del Castilho, a Rio de Janeiro neighborhood, where the interviewee has delivered lectures.

SOS 3D COVID19 (SOS). This network started and had its headquarters at the Arts and Design Department of the Pontifical Catholic University of Rio de Janeiro. RHMS was a subnetwork from SOS for about two months.

***Brasil Contra o Vírus* [Brazil Against the Virus] (BCV).** When Leroy Merlin® in the Tietê region (in São Paulo) provided its Bricolab™ shared workshop, the network gained a substantial production capacity, making it their headquarters. Institutions provided special 3DP to produce Charlotte valves: Biofabris from the University of Campinas (UNICAMP), Institute for Technological Research – IPT, and Centre of Information Technology Renato Archer.

The network idealizer, Thabata Ganga, is a Biomedical Engineer and has developed and led several maker projects. There is a manifesto about the importance of open-source software on their website (*BRASIL CONTRA O VIRUS*, 2020).

Their teams used Telegram® to enable communications between eight specialized ramifications: 'Modelling', 'Printing and Prototyping', 'Production Supplies', 'Machining and Production', 'IT', 'Biomedical Engineering and Health', 'Legislation', and 'Hospitals and Public Managers.'

***Makers Contra a Covid-19* [Makers Against Covid-19] (MCC).** Having had its headquarters at Casa de Makers makerspace, they advocated for non-hierarchical autonomous behavior and also promoted the Brazilian Universal Healthcare System (SUS) as "the unique form of reassuring the population survival" (*Makers Contra a Covid-19*, 2020). MCC's first 3D model is called 'VIVA SUS V1', and one of their 3D models has the inscription 'NOT FOR SALE.'

***Trem Maker* [Maker Train] (TM).** They describe themselves as "makers and enthusiasts believing in the potential of Maker Culture and the importance of creative economy to the economic growth of Minas Gerais state" (*Trem Maker*, 2020). Daniel Lopes is the member who started the project. He is the founder of 3DLabs, a 3DP company. This network is the unique one in this study that also produced a Face Shield for selling.

3.4. Design guidelines

Next paragraphs indicate the design guidelines as the final result of our analysis. Each guideline is described by the key expression concerning the core idea behind it. Their originating group of RDM characteristics separates them. We describe the evidence(s) supporting each guideline in Table 4 below.

Product requirements. A *coordinating node* meant the ability to guarantee the regularity of output. Once approved the model, all network nodes were supposed to replicate that one with the demanded requirements.

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Final *user participation* since the beginning; in this case, healthcare professionals. Their inputs helped the initiatives to create and approve the PPE digital models quickly, leading the first batches production to take approximately a week.

Third, relying on open-source models was also fundamental to have a fast response to demand. We may understand this fact as a step forward to a "possible future" (Gasparotto, 2020, p. 69) scenario, where open manufacturing technologies will make the production scale flexible.

Enabling technologies. *Nodes diversity*: as seen in BCV, nodes with different capabilities allowed for a diversified output. Other networks, even those making different products other than Face Shields, were not observed using more complex technologies like those available at research institutions, for example, stereolithography (SLA) and digital light projection (DLP) 3D-Printers used in the case of CPAPNIVs.

Actor transformation. *Cultural aspect*: motivating the nodes to cooperate in a network. Four cases had statements in their websites about the maker's role or the Maker Movement as a fundamental enabler to overcome situations like the COVID-19 pandemic.

Process the demand using the online Google Forms™, which digitally stored the hospitals' information and provided a straightforward way to ask for donations.

The *multidisciplinary* character of the professionals composing the network. Usually, the network's ability to give an adequate response to a complex problem will be directly related to the diversity of professionals and their ability to deal with inputs from each other, which precisely represents this multidisciplinary capability.

Networked activities to produce PPE may have increased members' motivation to collaborate in maker processes. They may already have the necessary abilities: makers, researchers, engineers, designers, among many others. Nevertheless, as the interviewee from RHMS said:

> The importance of makers in society is to be able to bring innovation and collaboratively contribute to research. So, not only I contribute here in Brazil, but I can receive contributions from other countries (...). This was made very clear with these models of Face Shields.

Local enablement. *Institutional support,* which was fundamental to accelerate the networks' growth and capacity. Either at a shared workshop at Leroy Merlin® (BCV) or PUC-Rio's prototyping lab (SOS), once the network integrates this kind of resource, it grows in logistic capability, output volume, and even audience.

Actors and the community: at least one node have participated in a social project in all the networks, be it an individual maker like the interviewee from RHMS, be it a university department through extension programs, like Rio DESIS Lab.

Business Model. *Crowdfunding* has been considered an essential source of financing for start-ups, individual projects, and even a new type of philanthropy (Zhang, Tan, Sun, & Yang, 2020). With cases in this study, it was not different: besides institutional support, donations were also a fundamental growth enabler.

Confirmation of previous guidelines: because Business Model is the integrative element of the RDM framework, besides using alternative finance, Table 3 confirm previous guidelines, like user-participation, institutional support, and open development of products.

Table 4: Design guidelines

Group	Design guideline	Evidence
Product requirements.	*Coordinating node.*	Table 5 (Proximity) and Specificities: except for RHMS, initiatives had a central node as logistic center and headquarters.
	User participation.	Table 5 (User participation): Maker Networks had inputs from health staff in their designs.
	Open-source.	Table 5 (Digital [1/2]) and Specificities: Maker Networks used open-source models.
Enabling technologies.	*Nodes diversity.*	Table 6 (Capacity; Tools), Specificities and Description: The Maker Network showing the greater variety of nodes had access to more advanced machines, better exemplified by the case of BCV.
Actor transformation.	*Cultural aspect.*	Table 7 (Culture) and Specificities: Webpages or WhatsApp™ groups with messages about the importance of makers' collaboration in fighting the pandemic.
	Process the demand.	Table 7 (Communication): Except for RHMS, cases used Google Forms™ to process demand.
	Multidisciplinary.	Table 7 (Multidisciplinary): Maker Networks integrated professionals developing multidisciplinary projects.
	Networked activities.	Table 7 (Local networks) and the section of the RHMS member's interview transcribed in this article (after this table in 'Actors transformation').
Local enablement.	*Institutional support.*	Table 8 (Institutional support) and Specificities: Except for RHMS, cases received institutional support, better exemplified by SOS and BCV.
	Actors and the community.	Table 8 (Social/Communities) and Specificities: Cases had members participating in some social project, better exemplified by SOS and RHMS.
Business model.	*Crowdfunding.*	Table 3 (RDM cost model; Alternative finance) and the article from Zhang et al.: better exemplified by BCV and MCC cases. Besides, all the initiatives could count on individuals' donations.
	Confirmation of previous guidelines.	Table 3: RDM product design and materials [1/2] columns confirm Product requirements and Enabling technologies derived guidelines. The remaining characteristics relate to members' interaction with society. As the networks depended on donations and donated the production, it possibly allowed members to feel part of a collective effort (Actors transformation-related guidelines). Besides, institutional support and alternative finance also confirm the idea of a relationship between the Maker Network and the people and institutions existing in the place this network is located (Local enablement derived guidelines).

4. CONCLUSION

RDM-Maker Networks represents a way people may participate in producing goods and services to overcome difficulties as those imposed by a pandemic, like the shortage of PPE.

We understand Maker Networks as a type of collaborative network (Manzini, 2012). These RDM implementations may increasingly allow communities to participate in resilient networks and not rely exclusively on mass-production oriented models. The networks analyzed here represent a small-scale distributed manufacturing where we have a "moderate volume manufacturing of products in multiple locations while providing mass customization" (Kumar, Tsolakis, Agarwal, & Srai, 2020, p. 11).

We derived design guidelines from Maker Networks operating in a level of stress never observed before since the dependency of organizations on global supply chains has increased since the late 1990s (Baldwin, 2012). Besides, the COVID-19 pandemic generated a type of disruptive environment. Organizations that operate in such extreme situations may generate insights on issues like "organizational processes of adaptation and prioritization, resilience (following an extreme event), and barriers to inertia (where organizations fail to respond)" (Hällgren, Rouleau, & De Rond, 2018). The pandemic influenced our observations and the resulting design guidelines. We consider that Maker Networks' operation under the pandemic may offer insights for a non-extreme scenario.

For instance, every university and research institute related here had to operate with a restriction of access to their buildings (Gusso et al., 2020). However, they managed to contribute by adapting to digital infrastructure, which exemplifies the digital side of RDM processes (Srai, Harrington, et al., 2016).

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This work contributes to the current literature on RDM implementation cases, which have been described only in Europe and India and often in a prototypical stage (Luthra, Mangla, & Yadav, 2019). The contributions we give to the theory are twofold. We have created a tool for qualitatively analyzing new cases of RDM implementations by translating "key RDM-Makerspace characteristics" (Hennelly et al., 2019, p. 543) into a series of questions. Besides, the design guidelines presented here may also contribute to observing and exploring other Maker Networks in terms of RDM features.

The design guidelines explored in this study may also provide initial input for decision-makers and policymakers worried about local resiliency and supply chain resiliency in future projects or investments. One of the main contributions of the *RDM-Maker Networks* studied here was providing relief to the shortage of PPE from the traditional and globalized supply chain. Implications for supply chain resiliency and design can be further explored.

Further research can also explore locality-related specificities and cultural aspects on cases, which would be useful to detail the RDM analysis in terms of Local enablement and Actor transformation, respectively, with the aim to refine the design guidelines or qualitative models concerning these characteristics.

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APPENDIX

Following, we present the complementary tables to section 3.2.

Table 5: Product requirements for each case.

Case	Proximity	Customization	Real-time	Innovation	ECE1	ECE2	ECE3	Digital [1/2]	User-participation
RHMS	Delivered by each individual member at National Institute of Traumatology and Orthopedics (INTO) and Hospital Municipal Evandro Freire.	No.	Approx. one week.	No.	Yes.	Yes.	Yes.	WhatsApp® group [Prusa files], see Prusa Research .	Prototype test and approval.
SOS	Representatives from hospitals in the Rio metropolitan area collected them at PUC-Rio.	No.	Approx. one week.	Yes, hot air gun to finish parts.	Yes.	Yes.	Yes.	Face Shield: see Prusa Research . Protective Goggle: see VIVALAB .	Prototype test and approval.
BCV	Face Shield: collected at Leroy Merlin® – Tietê by representatives from São Paulo city hospitals. CPAPNIV: collected in production nodes and delivered throughout Brazil by Instituto Motirõ.	Face shield: Yes, following physicians' recommendation. CPAPNIV: Yes, see Favero & Isinnova .	Approx. one week.	Face shield: Yes, following physicians' recommen-dation.	Yes.	Yes.	Yes.	Face shields: BCV design team. CPAPNIV: see Favero & Isinnova .	Face Shield: inputs on design and prototype approval. CPAPNIV: prototype approval.
MCC	Logistics and distribution team delivered to public hospitals in the metropolitan region of São Paulo city.	No.	Approx. one week.	Yes. On the digital model.	Yes.	N/A.	Yes.	Based on Prusa files, see Prusa Research .	Prototype test and approval.
TM	Logistics and distribution team delivered to hospitals in several cities from Minas Gerais state.	No.	Approx. one week.	No.	Yes.	Yes.	Yes.	Face Shield: see Prusa Research .	Prototype test and approval.

Table 6: Cases' enabling technologies.

Case	Capacity [units/day]	Maturity	Capability	Tools
RHMS	Approx. 35.	Advanced.	Yes.	3DP and Cutters.
SOS	Approx. 400 Face Shields and 65 Protective Goggles.	Advanced.	Yes.	3DP and Cutters.
BCV	Face Shield – 100 to 150 (3DP); 150 to 200 (Cutters). CPAPNIV – Approx. 60 to 70.	Advanced.	Yes. *	3DP, Cutters and vat polymerization 3DP (SLA and DLP).
MCC	Approx. 60 to 70.	Advanced.	Yes.	3DP and Laser Cutters.
TM	Approx. 400.	Advanced.	Yes.	3DP and Cutter.

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Table 7: Actor transformation characteristics of each case.

Case	Culture	Leader	Education	Multidisciplinary	Communication
RHMS	Yes. *	Yes.	Yes.	Yes.	Previously known health staff.
SOS	Yes.	Yes.	Yes.	Yes.	Online Google® Forms™.
BCV	Yes. *	Yes. *	Yes.	Yes.	Online Google® Forms™.
MCC	Yes. *	Yes.	Yes.	Yes.	Online Google® Forms™.
TM	Yes. *	Yes.	Yes.	Yes.	Online Google® Forms™.

Table 8: Cases' local enablement characteristics.

Case	Institutional support	Local networks	Social/Communities	Research	Students/ Experts	Schools/Libraries/Labs
RHMS	No, only individuals.	Yes.	Yes.	Yes.	Yes.	Yes. *
SOS	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
BCV	Yes. *	Yes.	Yes.	Yes.	Yes.	Yes. *
MCC	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
TM	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.