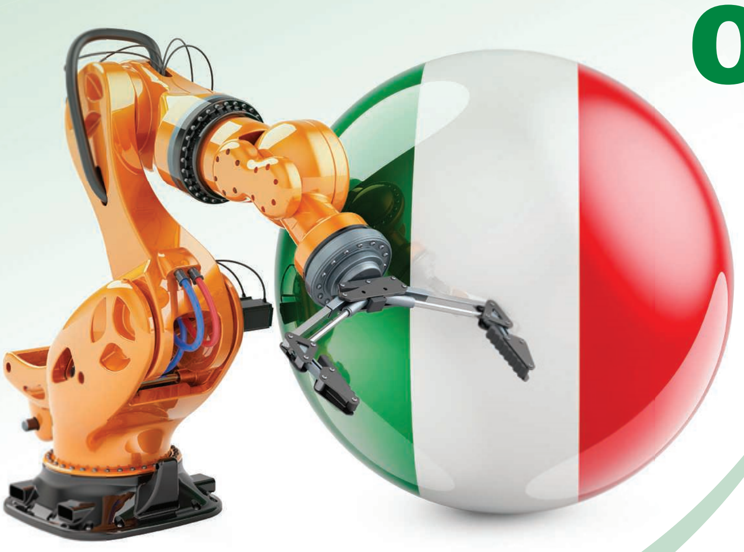

©SHUTTERSTOCK.COM/NATATRAVEL

# Making an Opportunity Out of a Crisis

*The Inclusive Approach of the Italian Robotics Community*

By Alessandra Sciutti, Fiorella Battaglia, Maria Rosanna Fossati, Valentina Calderai, Manuel Giuseppe Catalano, Gianluca Antonelli, Giorgio Maria Di Nunzio, Nevio Dubbini, Laura Giarré, Emanuele Menegatti, Francesca Negrello, Federica Pascucci, Monica Pivetti, Andrea Maria Zanchettin, Arturo Baroncelli, Salvatore Majorana, Carlo Marchisio, Bruno Siciliano, Paolo Rocco, Giorgio Metta, Claudio Melchiorri, Cecilia Laschi, Eugenio Guglielmelli, Alessandro De Luca, Paolo Dario, and Antonio Bicchi

## Introduction

The COVID-19 pandemic is forcing a rethink in robotics. In the form it is known today, robotics has been the prerogative of a broad community of insiders. But now, in the wreckage left behind by COVID-19, a new era is beginning. What does it hold? During the pandemic, increasing numbers of people had manifested the hope that robotics might bring novel solutions. And this interest has emerged beyond the usual boundaries of the experts or technology enthusiasts. This provides an opportunity to reinforce the community of people involved in the process of innovation. By involving citizens, the community becomes more comprehensive (that is, plural and diverse). This broadening will involve more practical knowledge and therefore produce better robots of many shapes and functions. If progress is possible in the industry, why not in the hospitals, shopping malls, restaurants, hotels, and schools? What is more, the approach endorsed by the Italian robotics community during the lockdown has established a new cooperation among those who labor with robots, and the professionals who work in hospitals, which is bound to last a long time. As a major impact, this experience will enable an improvement on science's relationship with and for society. This may entail a further shift: to value more scientific knowledge and scientific literacy.

In this article, we discuss how the robotics community of one country, Italy, has concretely responded to the pandemic outbreak in the early stages. Our aim is to analyze and disentangle the diverse elements that have contributed to making an opportunity out of a crisis. We also discuss how we are currently working to help the recovery phase and to share this experience with the worldwide community, passing along the many lessons learned.

Italy was the first western country severely affected by COVID-19 (see Figure 1), the implications of which were by no means clear from the outset. In early March 2020,

*Digital Object Identifier 10.1109/MRA.2021.3105639*
*Date of current version: 9 December 2021*

some people simply changed their schedules by postponing their commitments for a few weeks. Other people rushed to stockpile basic necessities and all sorts of merchandise. The awareness that some practices would have to change for a long time, maybe for good, struggled to dawn on most of us. Moving many activities to virtual and remote mode implied something dramatically different than simply replicating how these activities used to be "in person."

This scenario produced an unexpected, significant acceleration on the pervasive use of the wide variety of digital and communication technologies, smart devices for the Internet of Things, and the other most-advanced enabling technologies: robots and intelligent machines [5]–[7].

Resorting to robots seemed to everybody, not only robotics enthusiasts, the natural option to ensure safe interactions and avert the risks of infection [8]. This full endorsement from ordinary people fueled serious reflections within the robotics community, including a renewed interest for a global strategic orientation.

Over time, with the progressive diffusion of COVID-19 worldwide, robots found applications in responding to a wide variety of challenges brought by the pandemic. Robots are now involved in diagnosis, screening, disinfection, surgery, telehealth, care, logistics, manufacturing, and broader interpersonal problems unique to the lockdowns. A recent, comprehensive review of such applications can be found in [15]. For a further overview of the worldwide activities in robotics related to COVID-19, readers may refer to the works of Zhao et al. [16], Khamis et al. [17], and Hager et al. [18].

However, in the very first days of the outbreak of COVID-19, when it was not yet considered a pandemic and the phenomenon in Europe was constrained to Italy, the general reaction was a strong sense of responsibility, urging us to put technologies at work to help in the many emergencies that had to be faced. A true call of duty, further spurred by the media, with popular newspapers asking pointed questions, such as, "But where did they end up, these famous robots, now that they are most needed?" [20].

The Italian community of roboticists from both research and industry, united in their work at the Italian Institute of Robotics and Intelligent Machines (I-RIM) (http://i-rim.it/en), has responded to the challenge in a forceful manner. First, for the purpose of discussing the immediate responses and longer-term strategies, beginning on 26 March 2020 and for the first several weeks, the community began meeting weekly in a General Assembly to conduct daily videocalls with dozens of participants.

During these meetings and in intensive parallel exchanges in the community, different approaches to devising an emergency response were pondered. There are plenty of lessons to be learned from the past on top of which to build [1], while not disregarding inspiration, which may come from visionary literature [3]. A third, complementary approach that was at the core of I-RIM's strategy was based on the recognition that precious knowledge about the benefits and risks of applying robotic solutions does not belong to roboticists alone; rather, it is shared among many stakeholders and interest groups [4]. A "community-driven approach" in the field of robotics should cover multiple levels of citizens' engagement: from raising awareness about what present-day technology can do, to encouraging citizens to participate in the technological process by observing, describing, and analyzing how their living and working conditions have been changing, right up to setting the robotics agenda and road map for co-designing robotic solutions. It was felt that synergies should be established at different levels, involving

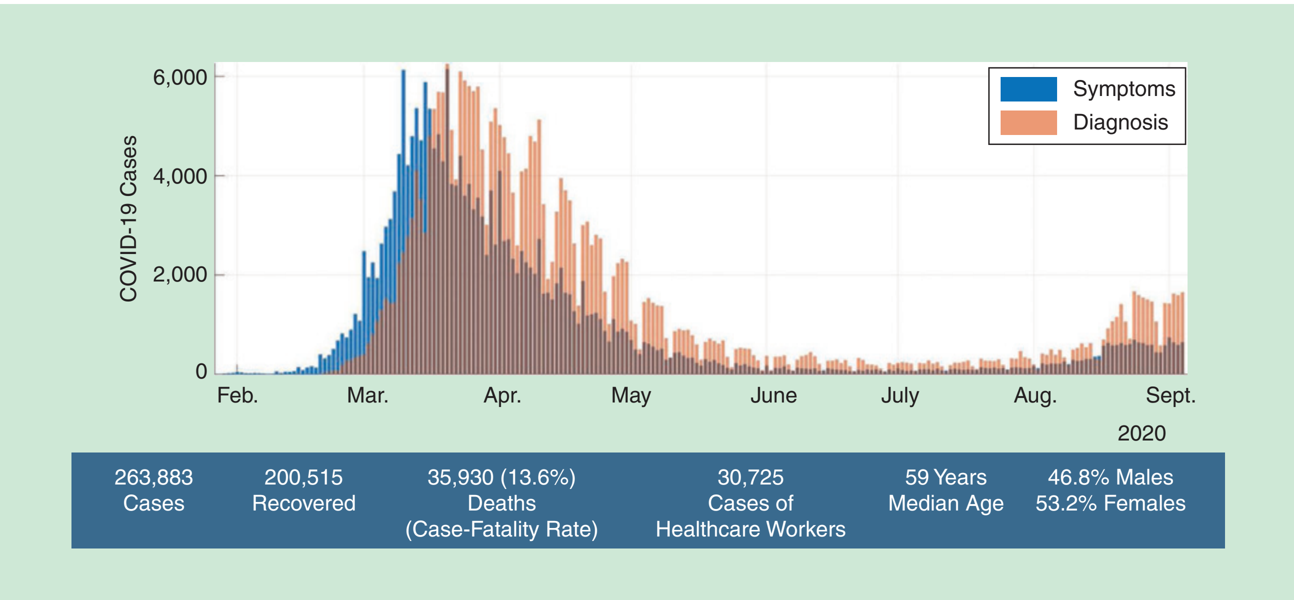


**Figure 1.** The cases of confirmed COVID-19 infection in Italy. The columns represent the cases by data of diagnosis (red) and by date of symptom onset (blue). (Source: Istituto Superiore di Sanità [1].)

designers as well as users, university researchers, and open source digital craftsmen.

The results of these actions were undoubtedly of some utility in the immediacy of the facts and have raised social interest and appreciation. Most importantly, perhaps, the lesson learned from the first phase (lockdown) is the overall philosophy of "citizen robotics" [19], a widely participated approach to robotics, which has been triggered by the COVID-19 outbreak at a rapid pace. Citizen robotics is the result of 1) surprise, 2) initial reaction, 3) a shared awareness about the social benefits of robotics, and 4) the state of the art of robotics, which didn't measure up to the challenges posed by the outbreak. Against the pandemic backdrop, the relationship of robotics with and for society grew deeper. Moreover, we believe this dramatic experience can have profound implications on robotics as a scientific discipline—both as a profession and a practice—which calls for further, deeper consideration in the near future.

## Activities of I-RIM Against COVID-19

The Italian Institute for Robotics and Intelligent Machines (I-RIM) is a nonprofit organization of national stakeholders promoting the development and practice of robots and intelligent machines to improve citizens' quality of life and well-being. Established in July 2019, I-RIM started with 250 members and held its first conference and exhibit in Rome in October 2019, with 500 delegates attending the conference and many tens of thousands of people visiting the exhibit.

The COVID-19 emergency in Italy started with the first outbreak on 20 February 2020 (Figure 1). The highest peak was reached on 21 March 2020, with 6,557 new daily cases. In the weeks in which our country had experienced a condition of emergency never before faced, I-RIM had organized itself to ensure that robots and intelligent machines could be of concrete help to the sick, workers in the health-care system, and those who continued to produce essential services or who experienced uneasy conditions in their homes.

The ventilators that help COVID-19 patients are intelligent machines, as there are intelligent machines in some of the laboratories that test-collected swabs, which depend on a high level of automation. But the occasions in which robots and intelligent machines could be useful are many more, and it is our duty to do everything possible so that they are helpful today and are ready to avoid and limit similar future situations.

The difficulties for an intervention of the necessary size—hundreds of hospitals and hundreds of thousands of people involved—in the very short time of the emergency, were obviously enormous. The unavailability of material stocks and the logistical difficulty of bringing machines and robots to places where they could be useful in a short time were among the major causes of this difficulty.

Nonetheless, the I-RIM community has strongly believed that useful contributions can be made by uniting all the forces that design and produce advanced technologies, artificial intelligence (AI), and robotics in Italy, Europe, and worldwide.

The three following concrete actions put into place by I-RIM, in coalition with different stakeholders (Figure 2), are

1) *A collection of needs*: a compilation of the demands and needs of health-care workers, of those who kept working in different sectors, and of those who remained isolated at home. The collection was organized using an anonymous questionnaire and more in-depth interviews of hospitals staff to understand what was needed to live and work in greater safety, with better results, or even to psychologically experience such a dramatic event better.
2) *A tech review*: a collection of "pilot projects" on the I-RIM website. There are dozens of examples of technological demonstrators, which are already tested in the clinical field. Additionally, the collection of technologies from different contexts that could support the response to COVID-19 and will reach a high technology-readiness level (TRL) in the medium term.
3) *An open coalition*: Since the beginning of the emergency, members and friends of the association—representing different stakeholders—met daily on an open platform. It was a sort of agora to brainstorm, share, and discuss possible solutions to actively fight the spread of the virus. These jam-packed meetings have been an inclusive network, able to sustain and stimulate the community. Moreover, with the collaboration of Maker Faire Rome—The European Edition and the makers community—the TechForCare platform was designed. It is a collection of simple and well-documented projects, available in short terms, which can be created with devices that are easily available even now. Its hardware and software solutions are made available free of charge by research centers, which can be assembled and used by nonspecialized personnel to solve concrete problems, even in small establishments located in less-serviced areas.

I-RIM tried to involve as many stakeholders as possible in different activities and delivered open outputs producing a leverage effect available for many recipients (Figure 2). In particular, all of the I-RIM activities designed to counter the pandemic's effects as well as all the information and data gathered are published on the I-RIM website (https://i-rim.it/en/i-rim-contribution), and the tools designed are in place to be implemented in the future. The outputs of the different activities are discussed in the next section while the outcomes are presented in the "Conclusions" section.

## Collection of Needs

Our goal of this action was to collect and understand the needs and requests of health-care workers, those who kept communities running or continued to produce under the lockdown, and those who remained isolated at home. An initiative based on interviews was started involving operators of hospitals and elderly care homes. A more systematic approach followed, aimed at understanding how life, and work in general, was changing during the peak of the COVID-19 outbreak. In the spirit of a truly user-centered design (UCD) process, an anonymous questionnaire was distributed around mid-April 2020 (https://bit.ly/2UoTi9N) and circulated among Italian citizens.

The main identified need was that of reducing the possibility of contagion in professional activities. The questionnaire sought to draft a picture of the tasks and routines people went through in different contexts as well as their subjective idea of the risks to which they were exposed. Roughly 200 people responded, describing how the pandemic influenced their life and work, the novel risks associated with their tools and environments, and how the interaction with colleagues and customers or patients was affected. Figure 3 describes the sample of the Italian population that responded to the questionnaire.

The answers to the questionnaire were mostly in a free-text format, so as not to bias the outcomes with forced choices. This posed a challenge to the manual analysis of results, which was undertaken with the help of natural language processing and data analysis tools [11]–[14]. The data and a preliminary analysis are available for further study by visiting the I-RIM website at https://i-rim.it/wp-content/uploads/2020/05/I_RIM_text_EN.html#topic=0&lambda=1&term. The code used in the analysis is available at https://github.com/gmdn/I-RIM. The respondents were mostly working in fields that were affected by the lockdown, such as health care, research, and education (approximately 30, 19, and 9%, respectively). Medical doctors, managers, consultants, teachers, professors, technicians, physical therapists, and other workers described how they had reorganized their activities. Roughly one third of the respondents had to

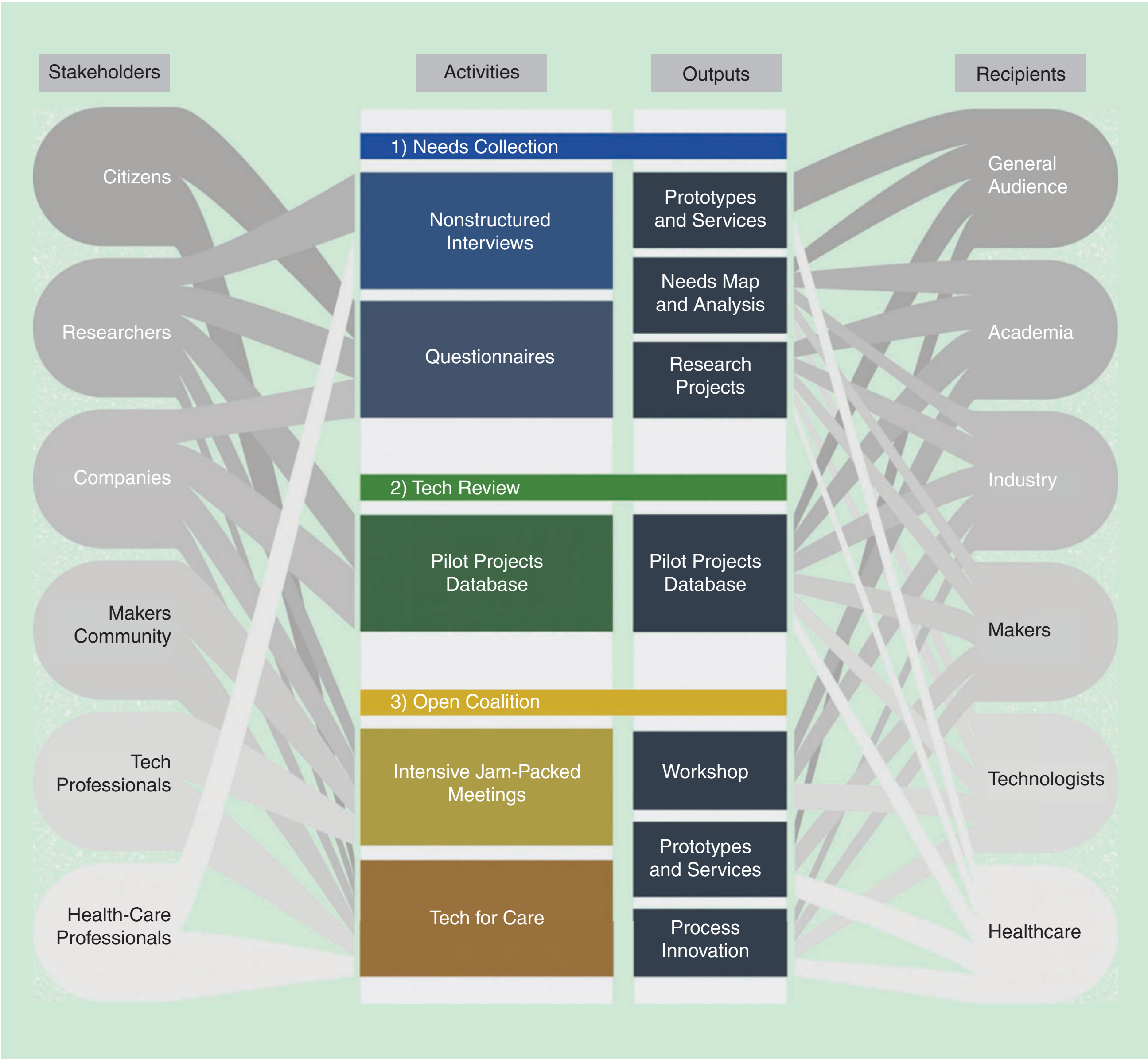


**Figure 2.** A diagram of the I-RIM activities and related outputs. The stakeholders' involvement and recipients of each output are also represented.

cope with the novel risks of potential infection in their normal work environment, or with traveling by public transport to get to work. The activities were found to have moved to smart working at a rate of approximately 50% of respondents, forcing many to abruptly switch to a new, virtual work dimension, characterized by the impossibility to naturally interact with colleagues, patients, and students (Figure 4).

Even in such difficult times (or perhaps because of them), the majority of respondents believed that technology, robotics, and AI could help in minimizing the risk of contagion (Figure 5). The questionnaire also asked for technical suggestions that could help to perform activities in a safer manner. The responses were different, ranging from the use of robots, to sanitizing environments or to handling objects at risk, to the deployment of technologies, to facilitating remote work, along with devices enabling faster medical testing and screening.

To summarize, the needs identified by the questionnaire were

A. remote encounters (communications) between people
B. remote work activities and/or personal protective equipment
C. the disinfection of objects
D. the disinfection of spaces
E. the tracking/monitoring of people, gatherings, and physiological conditions

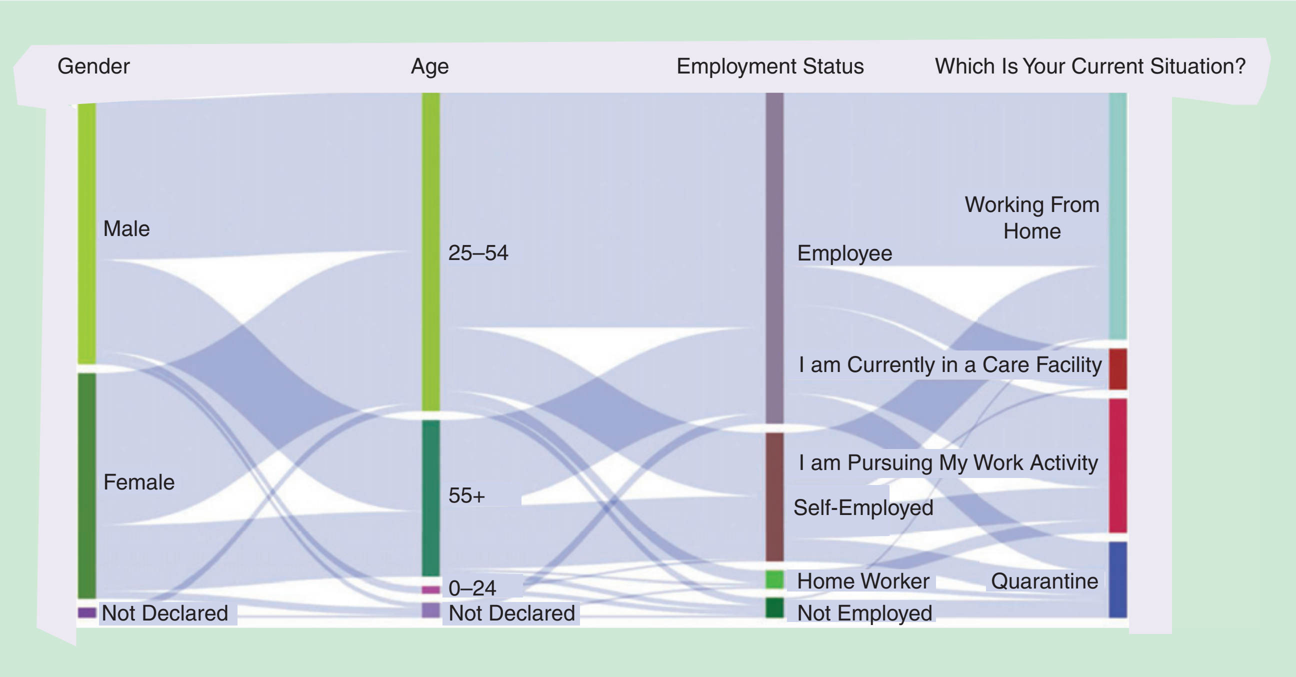


**Figure 3.** A demographic profile of the respondents.

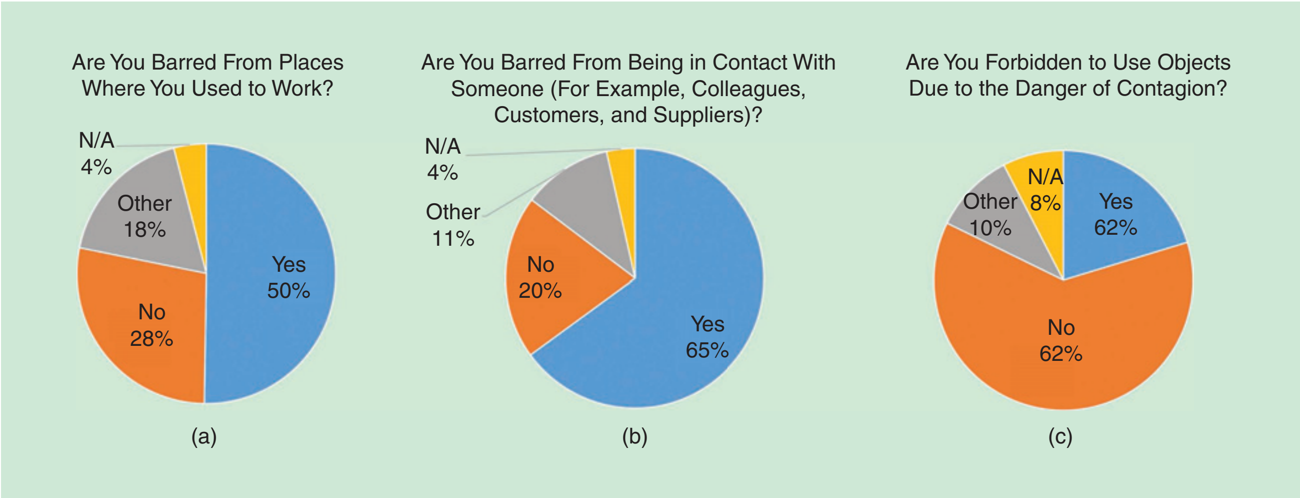


**Figure 4.** An example of questions about the participants' routine. From the answers, it emerges that COVID-19 had a stronger impact on the social aspects of life, that is (a) places and (b) people, rather than on the (c) practical ones (e.g., using daily-life objects).

F. the testing of a large number of swabs (including carrying out the test, and sample management and analysis)
G. home delivery.

The robots used for telepresence, for example, which could help in remoting encounters [Table 1 (need A)], were in high demand according to the results of our interviews and questionnaires. However, only a few units were available to hospitals in Italy at the time of emergency, and no companies were prepared to produce more of them in such a short period of time. I-RIM also collaborated with Istituto Italiano di Tecnologia (IIT) and the University of Pisa in promoting a telepresence robot avatar, which can be assembled with off-the-shelf hardware and open source software [Figure 6(a)].

In remoting activities (Table 1, need B), for example, Camlin Italy s.r.l. is bringing certification to ARC-Intellicare, an integrated and interoperable platform for home telerehabilitation, where wearable technologies and AI collaborate to offer the therapist the possibility to completely customize the therapy. The patient can perform at-home rehabilitation under the continuous supervision of a virtual physiotherapist who analyzes the exercises performed in real time (a telepresence module is, in any case, provided). Developed within a European pre-commercial procurement project [MAGIC (http://magic-pcp.eu/)] for stroke patients (it is currently at a TRL6, thanks to the multicenter clinical study Assisted Rehabilitation Care During Post-stroke mANaGement: fEasibiLity Assessment), the project has obtained a verticalization for post-COVID-19 patients at a TRL6 within a regional Emilia Romagna project (START again), integrating pulse oximeter and a library of respiratory rehabilitation exercises developed by the University of Marche, which is approved for post-COVID-19 patients and adopted in the clinic. The clinical trial currently underway will bring the project to a TRL7 (March 2021), with certification as a Class 1 medical device under MDR 2017/745. TRL8 is expected in late 2021 and as certification in Class 2a. Its integration into the telemedicine platforms of leading companies in the sector is underway.

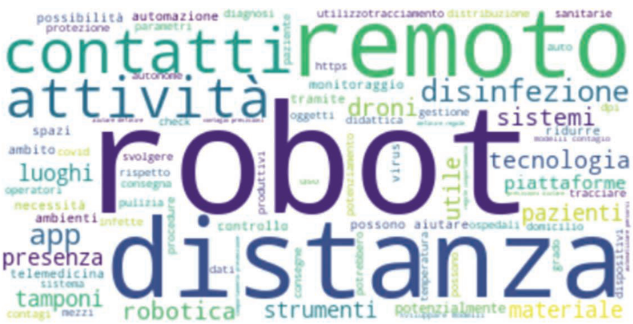


**Figure 5.** The wordcloud resulting from answers to the questions Do you believe that technology can help to minimize the risk of contagion? If yes, do you have any suggestions? Please briefly describe the solution you would suggest. Although it is not possible to fully translate the wordcloud without a loss of information, we highlight that the five most relevant words are robot, distance, remote, contacts, and activity.

Currently, the IIT community works on personal protective equipment (Table 1, need B), such as reusable, easily disinfectable protective masks (from off-the-shelf, full facemasks), and a lung respirator for emergency situations [the data are shared on the Digital Innovation Hub Hero Platform (https://dih-hero.eu/)].

With regard to the emerging necessity to sanitize objects or enable no-touch technologies (Table 1, need C), Ribes Tech is currently launching the Daphne Project, a no-touch button for lifts (http://www.ribestech.it/). On the other hand, to face the emerging need to disinfect spaces (Table 1, need D), the SANITIZE Project, supported by the Emilia Romagna region (Fondo europeo di sviluppo regionale structural funding), is about the realization of an automated system able to provide a rapid and effective disinfection using ultraviolet-C (UVC) light in environments particularly at risk, where it is not possible to carry out this operation through human intervention. The device is currently equipped with a completely autonomous navigation system and does not require floor traces or magnetic references. The sanitization system consists of an array of lamps capable of emitting radiation with a wavelength of 253.7 nm, exploiting the germicidal properties of UVC rays to break down the viruses, bacterial loads, molds, and fungi present on the action surfaces with an inactivation rate of 99.99%, through the

**Table 1. Examples of representative robotic solutions and their application field. Each platform is associated to the related technology and the need it is designed to address.**

| Name | Organization | Technology | Application Field | Need |
|---|---|---|---|---|
| LHF-Connect | IIT/Unipi | A telepresence robot | Hospitals | A |
| ARC-Intellicare | Camlin Italy s.r.l. | An interoperable platform for home telerehabilitation | Health care | B |
| Daphne | Ribes Tech | Touchless technology | A no-touch button for lifts | C |
| SANITIZE | Modis (Adecco) | Disinfection by ultraviolet-C light | Logistics, public premises | D |
| AI thermometer | IIT | AI | Public-spaces monitoring | E |
| YuMi | Politecnico di Milano | Automation | Sample processing | F |
| Yape | e-Novia | Mobile robot | Delivery | G |

destruction of the genetic material (DNA or RNA) of the micro-organisms. The final aim of the project is the creation of robot-to-robot intercommunication systems and the achievement of fleet operations for the purpose of improving the efficiency of sanitation operations.

The other projects from IIT support the diffusion of technologies useful in tracking and monitoring persons and gatherings (Table 1, need E). They include, for example, a technology based on computer vision and machine learning to improve and simplify automatic temperature checks, a social-distancing bracelet to keep a safe distance among people (https://www.iit.it/iit-vs-covid-19), and 3D-printed components for respirators, such as splitters, masks, and flowmeters.

During the emergency phase, ABB's collaborative robot, YuMi, supported hospitals in COVID-19 serological testing

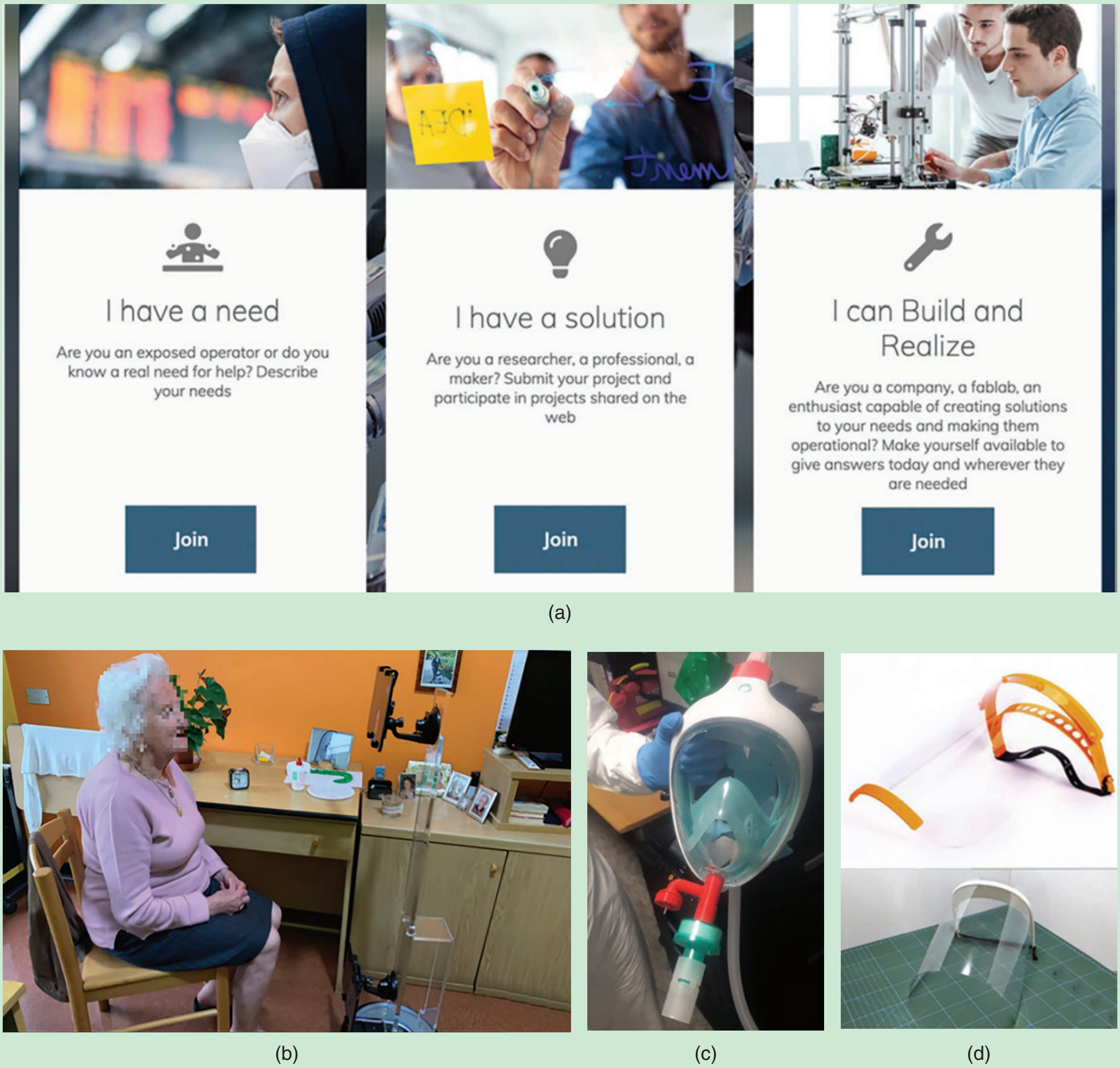


**Figure 6.** (a) The TechForCare platform and (b)–(d) examples of its active projects. (b) An LHF-Connect telepresence robot helps a patient's relatives communicate in the Azienda Speciale Per La Farmacia E I Servizi Sociosanitari (ASFARM) elderly care home of Induno Olona (Lombardy, Italy). The robot was realized under strict lockdown conditions by ASFARM personnel using open software and instructions published by researchers of IIT and the University of Pisa with the support of I-RIM. (c) The Department of Information Engineering and the Department of Medicine of the University of Padova (Italy) developed UNIPD-Mask: a set of valves that allows converting EasyBreath, the snorkeling mask developed and marketed by Decathlon, into a continuous positive airway pressure mask. (d) A collection of methods to produce face shields using different production techniques. (Source: TechForCare; used with permission.)

(Table 1, need F). This application can automate up to 77% of the testing actions and helps analyze up to 450 samples per hour with no laboratory technicians involved (which can lead to health issues). The project was designed at Politecnico di Milano, in partnership with ABB and the European Institute of Oncology in Milan.

A specific solution for delivery is Yape (e-Novia), even if it was not specifically developed in response to the pandemic. An autonomous logistic vehicle for contactless goods transportation adapted to the COVID-19 emergency is presented in [2]. In Table 1, we list a few robotic solutions, among those mentioned in this section or reported in pilot projects on the I-RIM website, to address the main collected needs.

**AI for diagnosis and treatment is the most developed field, perhaps because it does not necessarily rely on advanced hardware platforms.**

Since the beginning of May 2020, activities have progressively restarted. The needs and priorities of citizens have been changing accordingly: Some workers have moved back from smart working to their "in-presence" job, while others have restarted their activities after full closure. Novel challenges are posed by COVID-19 to sectors like education, tourism, culture, and commerce, which need to be addressed. A new questionnaire, made by an I-RIM UCD working group, is currently circulating to capture these changes over time and intercept the needs and hopes of all the involved actors. The questionnaire is open and available on the I-RIM website, and the results will be published there.

## Tech Review

A window on what robotic and intelligent machines may perform to counteract infectious diseases was opened on the I-RIM website, with a collection of pilot projects (https://i-rim.it/en/pilot-projects) presented by companies and research groups in Italy and worldwide. The pilot projects are technological demonstrators with a high TRL [21], i.e., already tested in the clinical field or in relevant environments, which can be brought to commercialization and made available for generalized use in the medium term. The projects are classified based on the application field, geographical region of origin, developer, and TRL. Moreover, each project has a dedicated page where a short description is accompanied by links to the related technology and application examples.

The database, including more than 70 applications of robots and intelligent machines, can be analyzed by filtering the entries according to one or more of these categories. The

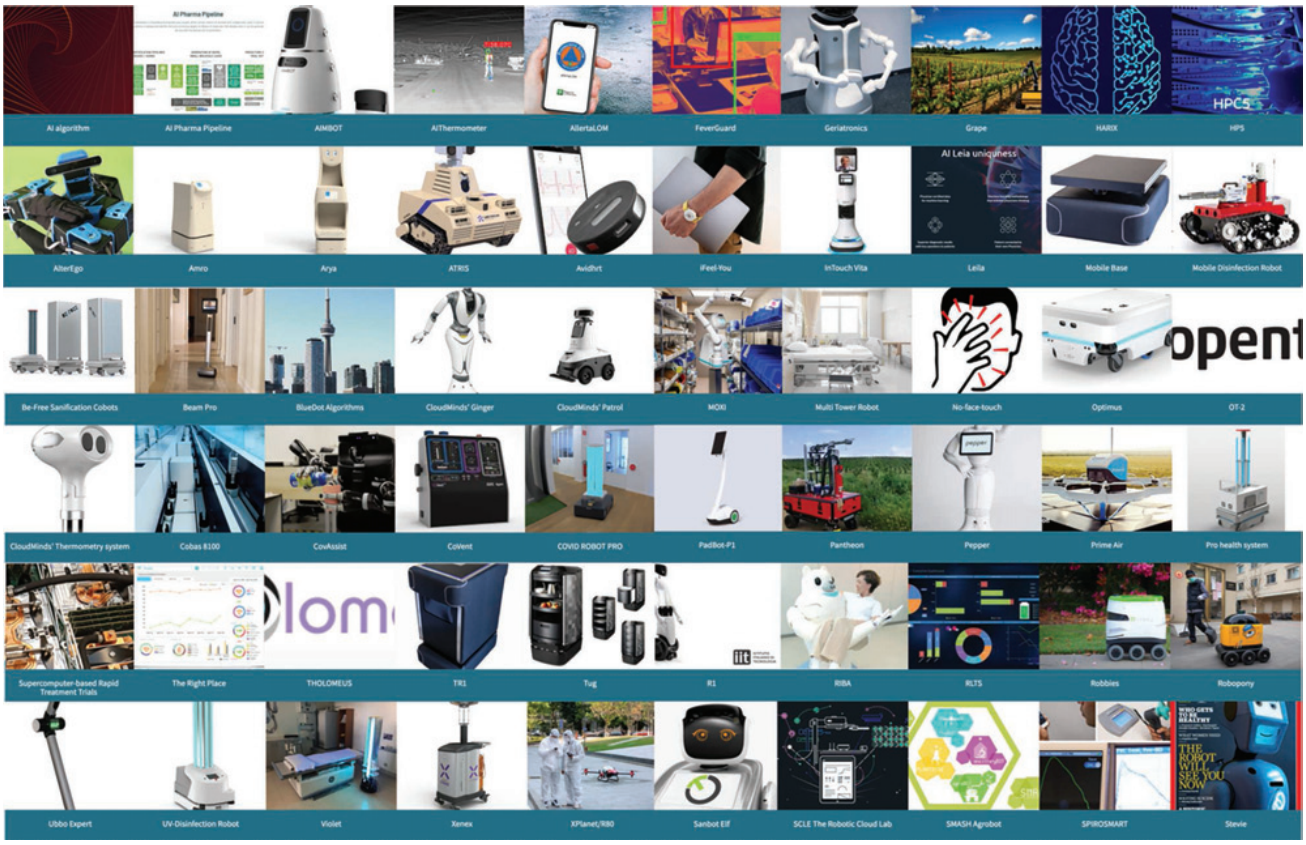


**Figure 7.** Examples of robots and intelligent machines from the Pilot Projects database.

new projects can be added by developers autonomously and are validated by the I-RIM staff.

Figure 7 provides some examples of projects extracted from the database. One can immediately notice the variety of the systems shown, which is directly related to the number of applications that roboticists and practitioners have envisioned for fighting COVID-19.

To provide a quantitative evaluation of the distribution of new robotic technologies, Figure 8 reports simple statistics of the collected data. Our analysis includes projects collected from all over the world to obtain the most comprehensive set of technological demonstrators. The geographical distribution highlights a relevant number of Italian initiatives, which is related to the specific interest of the I-RIM community.

Within our search, we identified nine different application fields for robotic technologies. It is worth noting that the use of robotic technologies in the medical field and for environmental sanitation, which includes devices for monitoring people's health (29%); disinfection technologies (16.7%); and assistive robotics (15.3%); covers more than 60% of the applications retrieved. It is possible to identify that a second cluster of applications refers to those systems that prevent the physical contact among people during the pandemic outbreak, such as autonomous delivery (13.9%), companion robots (6.9%), and telepresence systems (6.9%).

Given the relatively high TRL of the demonstrators, 87.5% of the projects are above TRL6, most of the projects in the database involve companies and start-ups (75%), while only a few have been fully developed by research institutes (25%).

Studying the relationship among the data collected, it is worth noting that most of the fields have demonstrators at various TRLs, except for the telepresence systems and smart hospital managers, which already had a market as videoconference and management tools, respectively (Figure 9). AI for diagnosis and treatment is the most developed field, perhaps because it does not necessarily rely on advanced hardware platforms. Assistive, companion, and agricultural robotics are at the forefront of research and innovation, with most of the results having a TRL ≤8, which identifies those systems that are functionally complete and operational but are not yet in large-scale production.

The pandemic outbreak resulted in the need for robots and intelligent machines to respond to new social rules, like physical distancing; intensive object and environment disinfection; physiological data acquisition for monitoring and tracking the infections; and practical issues, such as the scalability of swab-test analysis (see the "Collection of Needs" section). Another important aspect is that the robots need to be deployed in hospitals, shops, and in everyday life contexts, which differ from their traditional application fields, e.g., industrial production lines and logistics.

From our analysis emerged that the technologies related to sensing, monitoring, computation, and data management are the most ready on the market. Some robotic technologies exist to answer the needs of autonomous delivery, e.g.,

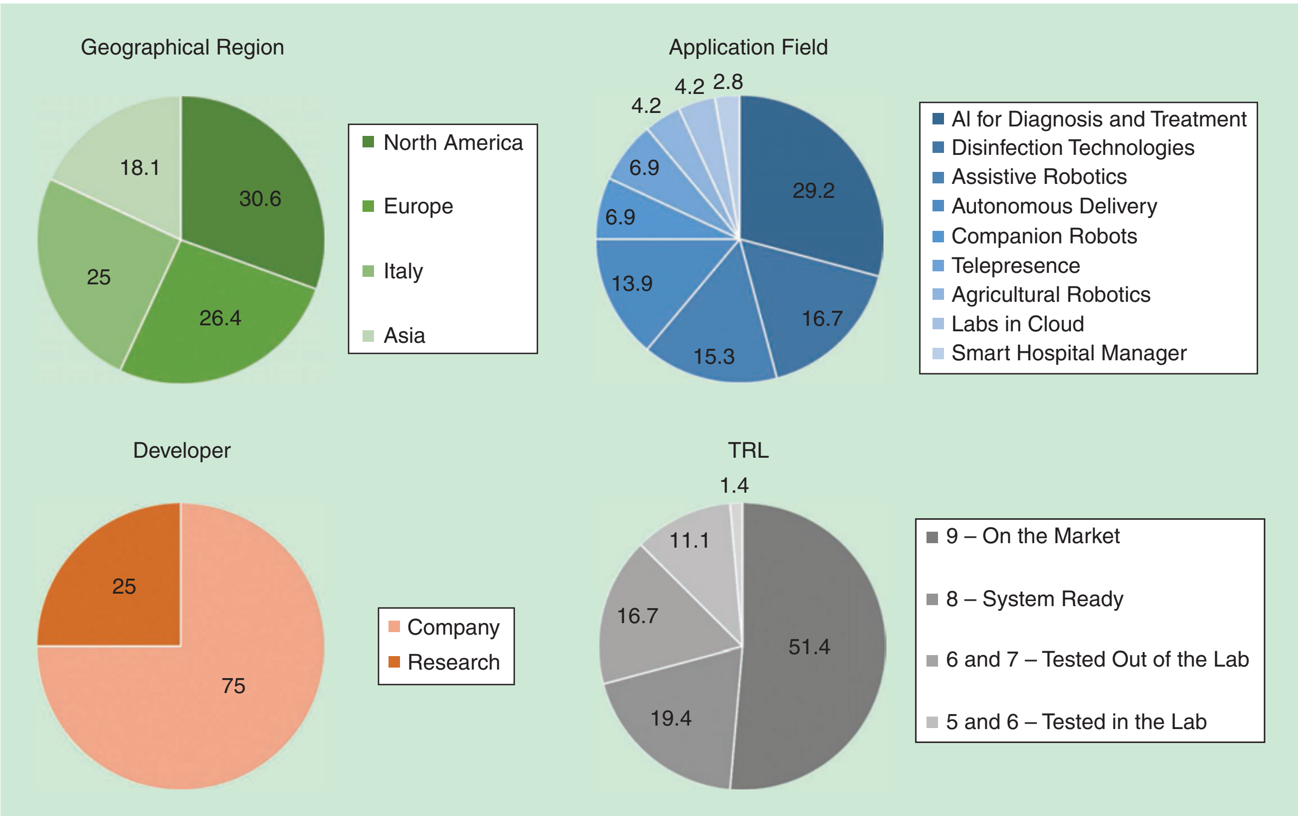


**Figure 8.** The percentage distribution of the pilot projects by geographical region, application field, developer, and TRL.

automated guided vehicles for industrial logistics or collaborative robots, but an effort is required for porting them to every-day home environments.  For other systems, like assistive robots, although there is not yet an established market, many solutions exist at the prototype level or an early production stage, and it is necessary to enhance the maturity of robotic solutions.

Despite the number of national and international initiatives, our analysis showed that the impact that robotics and intelligent machines could have had during the crisis was also limited by three factors: 1) the state of the art only allows for reliable and effective performance in limited, controlled, and well-defined tasks; 2) these systems often require assistance by technologically skilled people; and 3) even existing technologies were not widely available during the pandemic outbreak.

We believe that only a substantial further investment in research and innovation can successfully tackle the first and second issues (see [1]), fostering a UCD approach to citizen robotics. For a response at the height of the pandemic outbreak, I-RIM dedicated a special emergency effort, as described in the next section. We would like to highlight that this activity started to answer the needs of the Italian community during the outbreak, but from the beginning, the database has been compiled in both Italian and English to enable a broader audience to benefit from it and hopefully foster novel, interdisciplinary collaborations after the outbreak.

However, the solutions listed in the paper are considered "stand alone," while we point out the systemic approach adopted by the Italian robotic community. This approach is unique because it is a direct consequence of the well-established links among different research groups in different universities and the coordination of the national robotics society (I-RIM).

## Robots in Emergency and Open Coalition

A workshop (https://www.youtube.com/watch?v=O_yZH1JUAI8) was organized on 28 May 2020 by the Italian Chapter of the IEEE Robotics and Automation Society and I-RIM to reflect on the successes and shortcomings of technology in the lockdown phase, and to prepare for the next challenge—a safe economic recovery. The workshop aimed at restarting a dialogue between industry and academia based on the requests of the stakeholders. The three main areas of interest were agriculture, manufacturing, and health care. During the workshop, stakeholders had the opportunity to express their needs, while academy and industry proposed their solutions.

The difficulties of a robotic intervention of the appropriate size in the extremely tight time frames of the emergency were obviously enormous. This is not only a technology problem (pilot projects prove that there exist technical solutions which, albeit limited, could be useful), but also a logistical gap. There were simply not enough robots yet on the market.

Nevertheless, the I-RIM community made an endeavor to bring together all the forces that design and produce advanced technologies, AI, and robotics in Italy; Europe; and across the world; with the aim of making a useful, even if not very ambitious or sophisticated, contribution. The idea was to collect simple and well-documented robot projects, using off-the-shelf hardware easily available during lockdown (e-commerce never stopped delivering in Italy) and open software made available free of charge by research centers. Most importantly, these robot projects could be assembled and operated by nonspecialized personnel to solve concrete problems in the actual environment of our hospitals and elder care homes in the suburbs. To make this possible, I-RIM launched TechForCare, a common space or coalition (https://i-rim.it/en/short-term-solutions), aimed at bringing together the

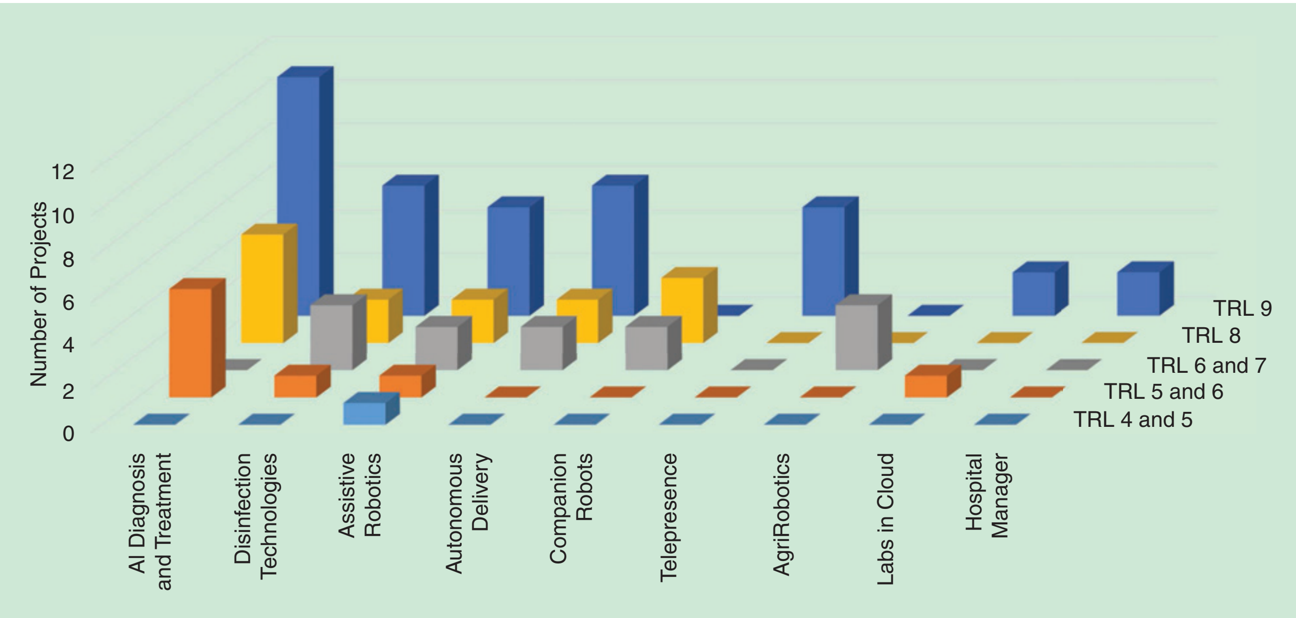


**Figure 9.** A histogram showing the relationship between the application field and the TRL of the pilot projects.

innovation capacity of communities of experts in new technologies with the pressing needs of all operators involved in the emergency. The TechForCare web platform (https://techforcare.com/en), built by I-RIM in collaboration with Maker Faire Rome (a meeting point for the community of makers and innovators in Italy), offers a selection of resources, solutions, technologies, intelligent machines, and robots to fight the epidemic and its effects [Figure 6(a)].

The key idea underlying the TechForCare platform is to bring together needs and solutions. Once operators provide their needs, the platform makes a match with solutions and producers/FabLabs in the various areas to create prototypes and realize them.

I-RIM supported TechForCare in the evaluation of the projects by establishing a scientific committee. The committee is still active and is composed of four working groups: makers and biomedical/bioengineering, robotic, and ethics experts. Each working group evaluates a project considering different aspects. The makers evaluate the feasibility of a project in terms of the resources/effort required to produce it. The biomedical/bioengineering experts analyze healthcare solutions according to the certification requirements. The robotic experts assess the TRL of the project. Once a project is technically approved, the ethics experts complete the evaluation by assessing its alignment with ethical values and principles.

The selected projects are accessible and available to everyone, from healthcare professionals to manufacturers of essential goods and services. Anyone can either simply look through the available solutions or collaborate in defining new ones. As an example, the NoFaceTouch project [9] (SIRSLab, University of Siena) provides software that makes a smartwatch vibrate as soon as your hand gets close to your face, to avoid contacts at risk of contagion. A second example is LHF-Connect (IIT and the University of Pisa), which consists of a telepresence robot realized using a modified vacuum cleaner robot, two tablets, and few 3D-printed parts, together with free, open software for guidance and communication management between a patient, his or her family, and a volunteer robot supervisor. This system was replicated and deployed inside several COVID-19 hospitals and elderly care homes [see Figure 6(a)].

## Concluding Remarks

The world has changed and will continue to do so as it comes to terms with the pandemic and its aftershocks. The COVID-19 crisis has cast a new light on the existing tensions among the innovation, production, and fair distribution of private and public health resources. In normal times, the answer to this problem is typically constrained by a combination of incentives to innovation, the removal of trade barriers, and state intervention in favor of the most vulnerable parts of the population.

This precarious and partial equilibrium has been shaken by the restrictions to research brought about by intellectual property rights, the return to state protectionism (export bans, resource storage), and the collapsing of the transnational supply chain structure in the pharmaceutical and medical devices sectors, factors which have all hampered the fight against the pandemic outbreak [9].

At a hearing of the European Parliament on 21 April 2020, the Commissioner for Health and Food Safety, Stella Kyriakides, vigorously stressed both the need to encourage the production of medicines and medical devices in Europe, and to overcome the limits to European Union intervention in the area of public health policies, which are still essentially centralized at the member-state level. The I-RIM framework helps overcome these challenges by offering projects built around the expectations, needs, and ideas of people who are,


**Figure 10.** The network established in the Italian community and its outcomes. The term *citizen robotics approach* was used by Bicchi et al. [19] to describe the response of the Italian community in an e-letter published in *Science Robotics*.

in different ways, directly involved in the development of technologically advanced, inclusive responses to the demand for care and work in safety. In this sense, it can be a blueprint for similar initiatives at the European level, inspired by the awareness that a forward-looking innovation policy shall start from citizens' expectations and demands.

We believe that the I-RIM approach can also be an inspiration for science robotics research and for science-based, strategic, and large innovation projects featuring a distinctive mission-driven approach, which is fully in line with the ongoing planning methodology of the new European Research Framework Program (Horizon Europe). (The European and other international initiatives are collected on the I-RIM website at https://i-rim.it/en/other-convergent-initiatives.)

The activities put into place by the I-RIM in response to the outbreak were indeed not only considered as an immediate reaction to the urgency. Beyond rapidly providing devices for those in need, the activities established a new, more inclusive and connected vision on the field (Figure 10). The goal was to set the basis for a robust network in which robotics researchers, industries, makers, and interested citizens could exchange opinions, provide requests, and describe needs. Such a network, built in a moment of crisis, lives and will continue to live beyond the emergency, representing a common ground to avoid future crises.

Moreover, within the network, new opportunities have now emerged. During the COVID-19 meetings, robotics researchers and robotics industry had the occasion to meet, discuss, and find solutions together (beyond the single commercial projects) toward a more general common ground, laying the foundation for a new shared, comprehensive cooperation. Also, makers, robotics industries, and research now have a common platform of where to integrate their efforts, which, ideally, represents a widespread hub and direct bridge toward the needs of the citizens. Finally, a new channel of communication has been established between the robotics community at-large and society. This started in spring 2020 by exploring actual needs and asking for hints and suggestions. The citizens replied by displaying great interest and trust in the opportunities offered by the technology, especially in a time of crisis.

The main goal that we focused on is long term, i.e., to introduce robotics in novel contexts and activities, and involve nonexpert people in defining needs and proposing solutions (the idea behind the concept of "citizen robotics"). Beyond the technological solutions that the robotics community offered during the emergency, the core contribution we want to underline is about the different outcomes promoted by the I-RIM community (Figure 10), which implies a shift in the robotics paradigm: an invitation to stakeholders' active participation.

Indeed, to match up to the challenges brought by the changes associated with the pandemic, we need to establish a lively and open dialogue between society and technology. If citizens are demanded to join the scientific community to identify and respond to the new challenges, the world of technology must be ready to listen to and communicate honestly its shortcomings and successes. The aim should not be restricted to short-term analyses. Robotics and intelligent machines can be the key enabling technologies, not only for the future of health care, as widely experienced during this exceptional period, but also for a fully inclusive and sustainable society. We also need to focus on basic research to address the key problems of robotics and smart machines. Understanding what it takes for robots to be reliable, safe, trustworthy, and considerate of users—thus integrating them as effective components of our society—is the necessary step for robotics to be among us (and helpful to us) whenever a new and unpredictable challenge strikes at our existence, health, and quality of life, as COVID-19 has done.

## References


[1] G.-Z. Yang et al., "Combating COVID-19—The role of robotics in managing public health and infectious diseases," *Sci. Robot.*, vol. 5, no. 40, p. eabb5589, Mar. 2020. Accessed: Aug. 2021. [Online]. Available: https://www.epicentro.iss.it/en/coronavirus/sars-cov-2-dashboard, doi: 10.1126/scirobotics.abb5589.

[2] T. Liu et al., "The role of the Hercules autonomous vehicle during the COVID-19 pandemic: An autonomous logistic vehicle for contactless goods transportation," *IEEE Robot. Automat. Mag.*, vol. 28, no. 1, pp. 48–58, 2021. doi: 10.1109/MRA.2020.3045040.

[3] R. R. Murphy, "Robots and pandemics in science fiction," *Sci. Robot.*, vol. 5, no. 42, p. eabb9590, May 2020. doi: 10.1126/scirobotics.abb9590.

[4] "Rome declaration on responsible research and innovation in Europe (online) Link." [Online]. Available: http://ec.europa.eu/research/swafs/pdf/rome_declaration_RRI_final_21_November.pdf

[5] R. R. Murphy, V. B. Manjunath Gandudi, and J. Adams, "Applications of robots for COVID-19 response," 2020, arXiv:2008.06976.

[6] M. Tavakholi, J. Carriere, and A. Torabi, "Robotics, smart wearable technologies, and autonomous intelligent systems for healthcare during the COVID-19 pandemic: An analysis of the state of the art and future vision," *Adv. Intell. Syst.*, vol. 2, no. 7, p. 2000071, 2020. doi: 10.1002/aisy.202000071.

[7] Z. H. Khan, A. Siddique, and C. W. Lee, "Robotics utilization for healthcare digitization in global COVID-19 management," *Int. J. Environ. Res. Public Health*, vol. 17, no. 11, p. 3819, 2020. doi: 10.3390/ijerph17113819.

[8] S. Mazzoleni, G. Turchetti, and N. Ambrosino, "The COVID-19 outbreak: From 'black swan' to global challenges and opportunities," *Pulmonology*, vol. 26, no. 3, p. 117, 2020. doi: 10.1016/j.pulmoe.2020.03.002.

[9] N. D'Aurizio, T. L. Baldi, G. Paolocci, and D. Prattichizzo, "Preventing undesired face-touches with wearable devices and haptic feedback," *IEEE Access*, vol. 8, pp. 139,033–139,043, July 27, 2020. doi: 10.1109/ACCESS.2020.3012309.

[10] M. Anderson, M. Mckee, and E. Mossialos, "COVID-19 exposes weaknesses in European response to outbreaks," *BMJ*, vol. 368, p. m1075, Mar. 2020. doi: 10.1136/bmj.m1075.

[11] R. Mihalcea and P. Tarau, "Textrank: Bringing order into text," in *Proc. 2004 Conf. Empirical Meth. Natural Language Process.*, pp. 404–411.

[12] H. Jelodar et al., "Latent Dirichlet Allocation (LDA) and topic modeling: Models, applications, a survey," *Multimedia Tools Appl.*, vol. 78, no. 11, pp. 15,169–15,211, 2019. doi: 10.1007/s11042-018-6894-4.
[13] B. Srinivasa-Desikan, *Natural Language Processing and Computational Linguistics: A Practical Guide to Text Analysis with Python, Gensim, spaCy, and Keras*. Birmingham, U.K.: Packt Publishing Ltd, 2018.
[14] J. Silge and D. Robinson, *Text Mining with R: A Tidy Approach*. Sebastopol, CA: O'Reilly Media, Inc, 2017.
[15] Y. Shen et al., "Robots under COVID-19 pandemic: A comprehensive survey," *IEEE Access*, vol. 9, pp. 1590–1615, Dec. 2021. doi: 10.1109/ACCESS.2020.3045792.
[16] Z. Zhao et al., "Applications of robotics, AI, and digital technologies during COVID-19: A review," *Disaster Med. Public Health Prep.*, pp. 1–11, 2021. doi: 10.1017/dmp.2021.9.
[17] A. Khamis et al., "Robotics and intelligent systems against pandemic," *Acta Polytechnica Hungarica*, vol. 18, no. 5, 2021. doi: 10.12700/APH.18.5.2021.5.3.
[18] G. Hager, V. Kumar, R. Murphy, D. Rus, and R. Taylor, "The role of robotics in infectious disease crises," 2020, arXiv:2010.09909.
[19] A. Sciuti et al., "On combating COVID-19: A 'citizen robotics' approach from the Italian community," eLetter, July 2020. [Online]. Available: https://robotics.sciencemag.org/content/5/40/eabb5589/tab-e-letters
[20] R. Luna, "Ma che fine hanno fatto i Robot?" La Repubblica, Apr. 9, 2020. [Online]. Available: https://www.repubblica.it/tecnologia/blog/stazione-futuro/2020/04/09/news/ma_che_fine_hanno_fatto_i_robot_-299508476/
[21] "Technology readiness levels (TRL)," European Commission, Brussels, Belgium. Accessed: Aug. 26, 2021. [Online]. Available: https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

***Alessandra Sciutti***, Istituto Italiano di Tecnologia, Genoa, 16163, Italy. Email: alessandra.sciutti@iit.it.

***Fiorella Battaglia***, LMU Munich, München, 80539, Germany and Sant'Anna School of Advanced Studies, Pisa, 56127, Italy. Email: fiorella.battaglia@lrz.uni-muenchen.de.

***Maria Rosanna Fossati***, Istituto Italiano di Tecnologia, Genoa, 16163, Italy. Email: maria.fossati@iit.it.

***Valentina Calderai***, University of Pisa, Pisa, 56126, Italy. Email: valentina.calderai@unipi.it.

***Manuel Giuseppe Catalano***, Istituto Italiano di Tecnologia, Genoa, 16163, Italy. Email: manuel.catalano@iit.it.

***Gianluca Antonelli***, University of Cassino, Cassino, 03043, Italy. Email: antonelli@unicas.it.

***Giorgio Maria Di Nunzio***, University of Padua, Padua, 35121, Italy. Email: dinunzio@dei.unipd.it.

***Nevio Dubbini***, Miningful Studio s.r.l.s., 56023, Navacchio di Cascina (PI), Italy. Email: nevio.dubbini@gmail.com.

***Laura Giarré***, University of Modena and Reggio Emilia, Modeno, 41125, Italy. Email: lagiarre@unimore.it.

***Emanuele Menegatti***, University of Padua, Padova, I-35131, Italy. Email: emg@dei.unipd.it.

***Francesca Negrello***, Istituto Italiano di Tecnologia, Genoa, 16163, Italy. Email: francesca.negrello@iit.it.

***Federica Pascucci***, Roma Tre University, Rome, 00154, Italy. Email: federica.pascucci@uniroma3.it

***Monica Pivetti***, University of Bergamo, Bergamo, 24129, Italy. Email: m.pivetti@unich.it.

***Andrea Maria Zanchettin***, Politecnico di Milano, Milan, 20133, Italy. Email: andreamaria.zanchettin@polimi.it.

***Arturo Baroncelli***, Comau Robotics s.p.a., Grugliasco, 10095, Italy. Email: arturo.baroncelli@comau.com.

***Salvatore Majorana***, Kilometro Rosso s.p.a., Bergamo, 24126, Italy. Email: salvatore.majorana@kilometrorosso.com.

***Carlo Marchisio***, ANIPLA Milan Cinisello Balsamo, Milan, 20092, Italy. Email: automation@carlomarchisio.it.

***Bruno Siciliano***, University of Naples Federico II, DIETI, Naples, 80125, Italy. Email: siciliano@ieee.org.

***Paolo Rocco***, Politecnico di Milano, Milan, 20133, Italy. Email: paolo.rocco@polimi.it.

***Giorgio Metta***, Istituto Italiano di Tecnologia, Genoa, 16163, Italy. Email: giorgio.metta@iit.it.

***Claudio Melchiorri***, University of Bologna, Bologna, 40126, Italy. Email: claudio.melchiorri@unibo.it.

***Cecilia Laschi***, Sant'Anna School of Advanced Studies, Pisa, 56127, Italy and National University of Singapore, Singapore, 117575, Singapore. Email: mpeclc@nus.edu.sg.

***Eugenio Guglielmelli***, Campus Bio-Medico University of Rome, Rome, 00128, Italy. Email: e.guglielmelli@unicampus.it.

***Alessandro De Luca***, Sapienza University of Rome, Rome, 00185, Italy. Email: deluca@diag.uniroma1.it.

***Paolo Dario***, Sant'Anna School of Advanced Studies, Pisa, 56127, Italy. Email: paolo.dario@sssup.it.

***Antonio Bicchi***, Istituto Italiano di Tecnologia, Genoa, 16163, Italy and University of Pisa, Pisa, 56126, Italy. Email: antonio.bicchi@unipi.it.