UNIVERSITÀ DEGLI STUDI DI TORINO

Issue 3 (*CSR and Circular Economy as a remedy for companies fighting systemic crises*),
Volume 1, December 2020

ISSN 2704-9906

EJSICE

European Journal of Social Impact and Circular Economy

A Journal dedicated to the investigation and innovative research in Social Impact and Circular Economy fields.

Open access and available online at http://www.ojs.unito.it/index.php/ejsice/

Aims and Scope

The European Journal of Social Impact and Circular Economy (EJSICE) is an online open-access journal published by the University of Turin. The Journal publishes quarterly (every four months) articles that contribute to the development of both theory and practice of research methods used throughout the field of social impact and circular economy. The readers of this Journal are mainly researchers, academics, PhD students and other practitioners.

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Acknowledgments
All the Editorial Team is grateful with the anonymous reviewers for their valuable and constructive comments to the authors.

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Dear Colleagues,

Below the first special issue on "CSR and Circular Economy as a remedy for companies fighting systemic crises".
The Editor-in-Chief is grateful with the special guests:

- *Prof. Sonia Quarchioni;*
- *Prof. Sergio Paternostro;*
- *Prof. Silvana Secinaro*

for their valuable effort in conducting this special number.

Prof. Paolo Pietro Biancone

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In a period when companies have to deal with the adverse effects of the COVID-19 pandemic (Koonin, 2020; McKibbin & Fernando, 2020), the questions arises as to how Corporate Social Responsibility (CSR) can be a way out and a possibility for development and competitiveness in case of systemic crises (Hadj, 2020; Marín, Rubio, & de Maya, 2012; Vilanova, Lozano, & Arenas, 2009). This issue can be explored through three main research streams along the temporal dimension related to a potential crisis: ex-ante behaviors, in itinere behaviors, ex-post behaviors.

The first stream of research aims to investigate the companies' abilities to cope with the impact of a systemic crisis, while stressing their capacity of resilience. In this vein, attention should be paid to the effectiveness of risk management systems for responding appropriately to the crisis. Such effectiveness is influenced by difficulties in managing risks which are increasingly systemic in nature due to the strong interconnections between companies and society (Quarchioni e Trovarelli, 2013). Along these lines, one could explore whether and how CSR and/or the circular economy can help companies avoid systemic crises' effects by acting upon their capacity to understand risk interdependencies, as well as to withstand external shocks.

The second stream of research aims to investigate how socially responsible behaviors can be useful to alleviate the crisis' effects (such as the crisis from COVID-19) at least in the short period. In this perspective, companies can enhance virtuous behaviors towards both employees and customers (e.g. smart working for employees, contactless relationships with customers, etc.); they can undertake philanthropic projects (e.g. donations to hospitals, provision of essential medical supplies, etc.); they can promote specific business initiatives deemed as strategic in relation to the crisis (e.g. productive reconversion, production of essential goods, facilitated access to services, etc.).

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Finally, the third stream of research is focused on business ethics and sustainable development on which the current crisis is once again shining a light. Specifically, more insights are needed to understand to which extent this crisis can affect companies' implementation of CSR policies, actions, and tools, both in the positive and negative sense (Lamond et al., 2010; Kim & Li, 2014; Tencati, Perrini, & Pogutz, 2004; Yoon, Gürhan-Canli, & Schwarz, 2006). In this vein, studies could investigate possible organizational changes which could derive from the systemic crisis more or less directly. For instance, the current situation could push companies to rethink (and even radically change) their business models towards social responsibility and sustainable circular economy, thereby producing effects on the long term. In contrast, the current crisis could reinforce some negative effects such as those one produced by decreasing 'real' interactivity. More generally, companies could suffer the crisis rather than picking emerging opportunities.

In this regard, several topics can be identified that highlight the link between CSR and the crisis in the first place, and then the circular economy and the crisis. Addressing these topics can make the circular economy an opportunity in times of crisis and give rise to further research according to the above mentioned streams.

The call for paper of the European Journal of Social Impact and Circular Economy is aimed at advancing discussions on CSR social impact in times of crisis and on circular economy further. We welcome submissions from a wide range of theoretical, methodological and empirical approaches.

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The potential of circular businesses in the post-COVID era: a system dynamics view

Francesca Costanza[1]

[1] Department of Law (Palermo Campus), University of Rome LUMSA, Roma, Italy

E-mail: f.costanza1@lumsa.it

Received: 15/09/2020
Revised: 11/11/2020
Accepted for publication: 04/12/2020
Published: 18/12/2020

Abstract

The last decade has witnessed the flourishing interest of scholars and policymakers to the application of Circular Economy (CE) principles, which has been pointed out as a compelling goal for business and society at current times of Coronavirus pandemic. This paper aims to describe the roles of companies and consumers in CE implementation, the basic mechanisms of circular business creation and diffusion, and their potential contribution to the recovery post-COVID. For the purpose, it has been adopted a system dynamics (SD) view to build an insight model integrating selected literature inputs.

Distinguishing between "born circular" and "converted circular" businesses, model dynamics highlight the interplay of circular businesses and responsible consumers, postulating key feedbacks able to affect, respectively, the conversion of companies and people to virtuous productive and consumption behaviours. Finally, the consolidation of such mechanisms contributes to the alleviation of specific socioeconomic and environmental issues ascribable to the Coronavirus spreading.

Keywords: circular economy; circular business; COVID; system dynamics.

1. Introduction

The Coronavirus pandemic has been challenging global health care, economy and society. In order to minimize the loss of human life "in the face of an invisible contagion" (Sarkis et al., 2020, p.1), previous life routines have been substituted or integrated by new ones (e.g. sanitation, social distancing, use of disposable gloves and masks). The scenario observed in the early stage of COVID spreading (first half of 2020) included congestion of health facilities, national lockdowns and a generalized deceleration of production and trade, especially as far as the international commerce is concerned.

In this regard, the switch towards the Circular Economy (CE) principles, already felt as a compelling goal by policymakers in the pre-COVID era (e.g. European Commission, 2015, 2019; European Environment Agency, 2019), assumes a crucial importance at the time of writing this paper. In fact, once the initial shock was overcome, there is the need to cohabit with the virus in the medium term (until the development of a vaccine), balancing the urge to restore the economy with that of operating in safety conditions.

With a longer period orientation, to be proactive and to avoid being caught unprepared by potential system shocks, it is called for a general rethinking of production systems in terms of sustainability and resilience (Sneader & Singhal, 2020; Ellen MacArthur Foundation, 2020). Thus, national and local systems should accelerate the transition to Circular Economy (Blériot, 2020) attributing a central function to entrepreneurship, seen as a relevant change agent (Neumeyer et al., 2020). Indeed, the CE paradigm, subverting the traditional linear economy (summarized by the sequence of material extraction, transformation, disposal), introduces production and consumption practices devoted to resource recovery and re-circulation. This way, it promises to foster industrial efficiency and local supply resilience in an environmentally conscious way (Ellen MacArthur Foundation, 2013; Geissdoerfer et al., 2018).

This paper seeks to address circular business generative paths and their impacts on Coronavirus challenges by wearing strategic management lens, meaning that circular business development will be intended as a process involving firms and their environment (Katz, 1970; Mintzberg, 1987). So far, even in presence of extant contributions from the practitioners world (e.g. Ellen MacArthur Foundation), some gaps have been identified in the strategic management research dealing with CE.

In first place, the scientific literature originating the topic is not ascribable to the managerial and organizational spheres (Korhonen et al., 2018), and only recently the strategic management domain started to pay attention to CE, conceiving it as a driving paradigm for product and business model innovations (Linder & Williander, 2017; Urbinati et al., 2017). As a result, the research field is still young and not fully explored. Referring to a systematic literature review recently conducted by Centobelli and colleagues (2020), it was detected a research lack in providing a systemic view of circular businesses, considering multiple-actor interrelations and the contextual factors able to boost the transition. In addition, managerial contributions to CE conceptualizations are narrowly focused: they pay attention to just one side of the coin (companies), underestimating the crucial role of consumer acceptance of the new paradigm (Chamberlin & Boks, 2018).

This paper aims to concur in bridging the aforementioned gaps, seeking at the same time to make a contribution regarding some COVID related issues. Accordingly, three research questions have been formulated:

(1) What is the role of companies and consumers in the implementation of circular economy principles?

(2) What are the basic mechanisms of circular business creation and diffusion from a holistic perspective?

(3) In which ways the circular economy can contribute to the recovery post-COVID?

In order to address the above queries, it was adopted a system dynamics (SD) view (Forrester, 1961; Sterman, 2000; Wolstenholme, 1990) to build an insight model integrating relevant literature sources in a holistic and original manner. SD modelling approach was privileged because it provides visual and analytic tools to capture the feedback relationships among several variables.

The paper is organized as follows: after this introduction, it is proposed a literature review about Circular Economy and its potential links with COVID pandemic. Then, the methodology section describes SD features, together with the modelling approach for this study. It follows an illustration of research results, whereas core model dynamics are presented and described. Finally, the conclusion section summarizes the contents of the paper and the main contributions, highlighting limitations and future research avenues.

2. Literature review

The Coronavirus pandemic has caused health facilities overload, national lockdowns and a generalized deceleration of economic activities. The crisis has disclosed the fragility of many global supply chains and the need of more resilient supplies at a local level (Blériot, 2020). Moreover, the impact on business closures exacerbated social inequalities, whereas "minority groups and individuals living in poverty, including the elderly, are disproportionally affected by the resulting health and economic implications" (Neumeyer et al., 2020, p. 2). From the environmental perspective, together with a general call to preserve the environment as a precondition for public health (Wuyts et al., 2020, p. 2), the large-scale economic slowdown was claimed to bring more specific – and contrasting – effects.

On the one hand, it was registered an improvement of air and water quality (Saadat et al., 2020), especially in more polluted areas. However, such advancements are to be considered temporary and destined to gradually disappear with the necessary restart of economic activities. On the other side, there have been highlighted indirect negative effects, such as an increase of waste (in particular for disposable plastic goods and for protective equipments) and a reduction of recycling (Ragazzi et al. 2020).

In this context, sustainable development and CE are two related concepts (Geissdoerfer et al., 2017) assuming a crucial importance. Sustainable development, meaning to satisfy actual needs without compromising the satisfaction of future generations (World Commission on Environment and Development, 1987), is based on three pillars: economic growth, environmental protection and social inclusion (United Nations General Assembly, 2015). Entrepreneurships plays an essential role in pursuing sustainable development (Apostolopoulos et al. 2018), and, from a managerial perspective, the "triple bottom line" approach dictates for companies the joint consideration of economic, environmental and social performances (Tullberg, 2012).

Circular Economy, an approach postulating an economic system able to minimize resource exploitation, emissions and waste without compromising economic growth, is seen as a possible solution to address sustainable development (Geissdoerfer et al., 2018). CE mitigates the environmental externalities associated to economic activities, by providing guidelines to invert the logic of traditional, linear models where raw materials are extracted and transformed in finished products, consumed and finally routed to waste (landfilled or incinerated). Connaturated with this sequence are risks of material scarcity and negative environmental impacts: the CE paradigm overcomes such pitfalls by increasing product efficiency through new ways of production and consumption, where goods are conserved as long as possible and resources are iteratively circulated through closed loops (Guldman, 2016, pp. 9-11).

Accordingly, it proposes the redesign of products, services and business models, incorporating durability, re-use, repair, refurbishment, and recycling (Ellen MacArthur Foundation, 2013, 2015).

In spite of many Circular Economy applications from the practitioners world (e.g. Ellen MacArthur Foundation and Accenture), the scientific debate about CE appears dispersive. On the one hand, natural sciences and engineering fields have developed an ample body of research, routed in different research streams, such as: industrial ecology, acknowledging the need of operational learning from cyclical, renewable and cascading natural flows (Graedel, 1996); and cradle-to-cradle (McDonough & Braungart, 2003), a design strategy based on the consideration of products' entire value chains and life cycles, in search of eco-effectiveness (Braungart et al., 2007).

On the other side, conceptualizations in business, organization and management are still in an infant stage (Korhonen et al., 2018). Specifically, recent studies intersecting strategic management and CE only focus on circular business models (CBMs) (e.g. Linder & Williander, 2017; Crainer, 2013), i.e. business representations on how companies create, transfer and capture value relating internal and external relations (Zott & Amit, 2010; Osterwalder & Pigneur, 2010) suitable to put in practice CE principles by incorporating elements that slow, narrow, and close resource loops (Geissdoerfer et al., 2018).

Scholars contributions propose taxonomies of circular business models (Bocken et al., 2016; Urbinati et al., 2017), and highlight how CBMs are source of competitive advantage through the recovery of the so-called "uncaptured value" (Yang et al., 2016), that along linear business models is lost and not internalized. Circular business models allow to create and/or modify organizational and inter-organizational resource loops through three possible measures: (a) recycling, which allows to close loops instead of having open chains; (b) efficiency improvements (narrowing loops); and (c) use phase extensions, consenting to slow loops (Ellen MacArthur Foundation, 2013; Bocken et al., 2016).

So far, the strategic management studies have not addressed circular business development in a systemic way (Centobelli et al., 2020), i.e. taking into account factors affecting the circular business creation/conversion, and the relationships between differents actors, first of all the consumer, playing a crucial - and overlooked – role in the acceptance of CE (Chamberlin & Boks, 2018). Recently Geissdoerfer and others (2017, p. 765) reported that the typical subjects of Circular Economy's agency, i.e. entities needing to internalize and put in practice CE principles, are just government, companies and NGOs, thus underestimating the responsible consumer behaviour's role and its determinants.

3. Methodology

3.1 System dynamics modelling

The study addressed the research questions by adopting a qualitative system dynamics approach (SD) to create an insight model grounded in literature and representing a dynamic hypothesis about circular business spreading in relation to COVID related issues. Before illustrating modelling steps adopted for this research and describing the key model results, it is considered appropriate a brief introduction about system dynamics discipline and its building blocks.

System dynamics is a computational methodology grounded in cybernetics and system science, initiated at the MIT Institute (Boston) by Forrester (1961). In the context of this work, it was judged suitable to deal with Circular Economy issues, since it captures the behavioral dynamics of complex (social, economic and/or ecological) systems through the feedback relationships among the parts (Maier, 1998). The methodological choice was also supported by looking at numerous SD modelling efforts in the strategic minanagement field (e.g. Morecroft, 1984; Warren, 2005; Wang, 2011).

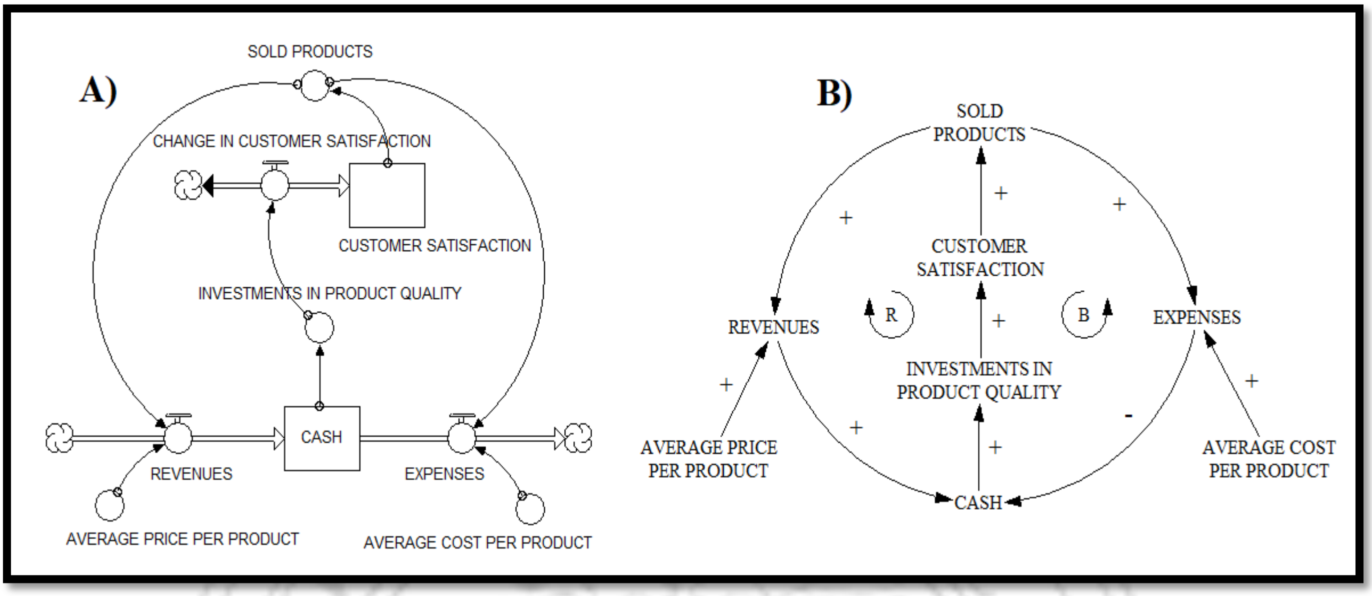
The SD modelling process (Sterman, 2000) involves the construction of stock-and-flow diagrams (SFDs) and causal loop diagrams (CLDs), paired with the formulation of differential equations allowing to simulate alternative policy scenarios.

In this regard, the phase of construction (and subsequent analysis) of SFDs and CLDs is acknowledged as a qualitative modelling branch of system dynamics (Wolstenholme, 1990), able to provide interesting results both as a stand-alone methodology or as preliminary step before mathematic formalization.

A stock-and-flow diagram is a map tracking networked processes of accumulation/depletion of material, information, and money (Sterman, 2000). It is made of stocks, flows and auxiliary variables. Stocks represent cumulated levels of resources or amount, are measured by quantities at a punctual time and are denoted by rectangles. Flows are the rates causing stocks to rise/exploit over the time, are measured by quantities per time unit and are graphically represented by mean of pipes inflowing or outflowing the stocks. Sometimes, especially in dealing with soft variables, modellers prefer to not keep inflows and outflows distinct, and to use bi-flow structures, expressive of stocks' net rates of change in term of difference between inflows and outflows (Sterman, 2000).

In the simplified shop economy of Figure 1, letter A), there are two stocks ('cash' and 'customer satisfaction'). The first is fed by the inflow 'revenues' and depleted by the outflow 'expenses' (assuming all the transactions taking place in cash); whilst the stock of 'customer satisfaction' is affected just by 'change in customer satisfaction' which is a bi-flow with its specific graphic.

Figure 1. Basic examples of stock-and-flow diagram (A) and causal loop diagram (B).



Source: Author's elaboration.

Auxiliaries, denoted by circles, are supplementary variables with various function: to help calculus through ratios and other formulas, to bring constant or exogenous parameters to the model, to synthesize system's partitions that the modellers decide not to focalize. Stocks and auxiliaries can impact on the flows related to other stocks, directly or through auxiliary variables. In the example, the stock of cash, ceteris paribus, impacts on the auxiliary 'investments in product quality', which in turn has a boosting effect on the 'change in customer satisfaction' and then on 'customer satisfaction'. The latter (together with other variables not included in this simple model), affects both 'revenues' and 'expenses' flows, and then the 'cash' stock.

On the right part of the figure above (letter B), it is shown a causal loop diagram. It consists on a network of interacting loops, synthesizing the model dynamics through a compact scheme which does not distinguish stocks, flows and auxiliaries, and isolates just some variables from the ones belonging to the stock-and-flow structure. In the example, the CLD shows the interplay of two loops, made of variables linked by arrowed polarities, whereas the positive and negative links mean that the cause-and-effect change goes respectively in the same and in the opposite direction.

Even loops have a polarity, resulting from multiplying all the links' signs. Loop R (positive polarity) is defined "reinforcing" because it shows virtuous or vicious mechanisms of continuous growth or decay: an increase of cash can induce new investments in product quality and thus sales, revenues, and ultimately more cash. On the other side, a cash depletion frees up less resources for quality investments and thus reduces sales, revenues, and again cash. Loop B (negative polarity) is "balancing" since it counteracts the above dynamics of growth/decay: more 'sold products' cause 'expenses' to raise, which in turn reduce the 'cash' stock. Viceversa, a reduction in sales has a depleting effect on expenses and thus a boosting effect on cash.

3.2 Research process

The study was based on an iterative process of literature selection and analysis, accompanied by model building activities. The starting point was a literature research about topics directly descending from the research questions: Circular Economy, consumer's role in Circular Economy, Circular Economy and Coronavirus.

As mentioned in the introduction, in line with research aims the analysis adopted strategic management lens. This means that every source was evaluated for its potential contribution to the circular business development discourse, treated as an interdependent process involving firms and their environment.

However, the phase of literature search considered both the strategic management orientation and the novelty of CE topic for the field, whereas theoretical developments are far from being complete, and a systemic view is lacking. As a result, the searching approach was multidisciplinary to also explore candidate inputs from other fields, such as environmental sciences, industrial ecology and product design.

Scientific sources have been selected from Google Scholar (or GS) according to the following criteria: relevance to the study purpose, published in peer-reviewed international journals, written in english language. Beside boolean researches on the database, other sources were identified by looking at papers' references.

The decision to use GS (instead of a subscription-based scholarly database, such as Web of Science, or WoS) is due to the following reasons. First, like WoS, Scholar is multidisciplinary (De Winter et al., 2014; Mikki, 2009) and this fits the purpose to embrace publications from many research fields, with more direct links to open access publications.

Second, GS aggregates both academic and grey literature (Haddaway et al., 2015), and this is useful given the actuality of the research and the fact that Circular Economy issues produce diverse types of output knowledge than just research articles. Indeed, it was considered worth to review also non-scientific sources, such as best practice reports and other publications from practitioners and policy makers, when considered coherent with the investigated objects and coming from authoritative and internationally recognized private/public institutions.

The documents (49 in total, published in the last decade) were analyzed in-depth, progressively identifying key concepts in relation to the research questions. Then, a series of candidate variables (retrieved from literature or elaborated by the author through inference from it) were listed, trying to hypothesize a modeling strategy for each, i.e. it was decided whether to represent every variable as a stock, a flow or an auxiliary, and key links have been identified. This phase was useful for a twofold reason: to create a preliminary understanding of the relevant system, and to drive the first modelling activity.

Afterwards, using a specific SD software, it was started the building of the stock-and-flow diagram. The modelling process was iterative and, starting from scratch, the model was continuously modified, adjusted and enriched in pace with new literature rounds and modeller's progressive undestanding of the investigated objects.

In the final version of the model (made of 31 variables: 5 stocks, 3 flows and 23 auxiliaries), it was decided to represent as stocks only variables ascribable to businesses and consumers, to remark accumulation/depletion processes regarding these key actors.

All the flows were modelled as bi-flows to make the qualitative model more immediate and compact. Auxiliary variables were used in two ways: to help in making feedback mechanisms explicit, and to show exogenous influences, i.e. not directly partecipating in any feedback circuit. Once the SFD was completed, it was outlined a comprehensive causal loop diagram made of 11 interacting loops, providing a holistic view of the model dynamics and allowing a better analysis, discussion and communication of research results.

4. Results

4.1 Stock-and-flow diagram

The first modelling output is the stock-and-flow diagram of Figure 2. Building on literature insights, the model postulates that the transition to CE is a process of "conversion" involving not only business companies, but also consumers. Therefore, the model mirrors changing processes occurring in both categories, their interactions and their contribution to post-Coronavirus recovery.

In first approximation, the model area is divided in four sub-areas, indicated by rectangular labels. On the left side, there are depicted processes of 'Conversion to responsible consumption', whilst the center of

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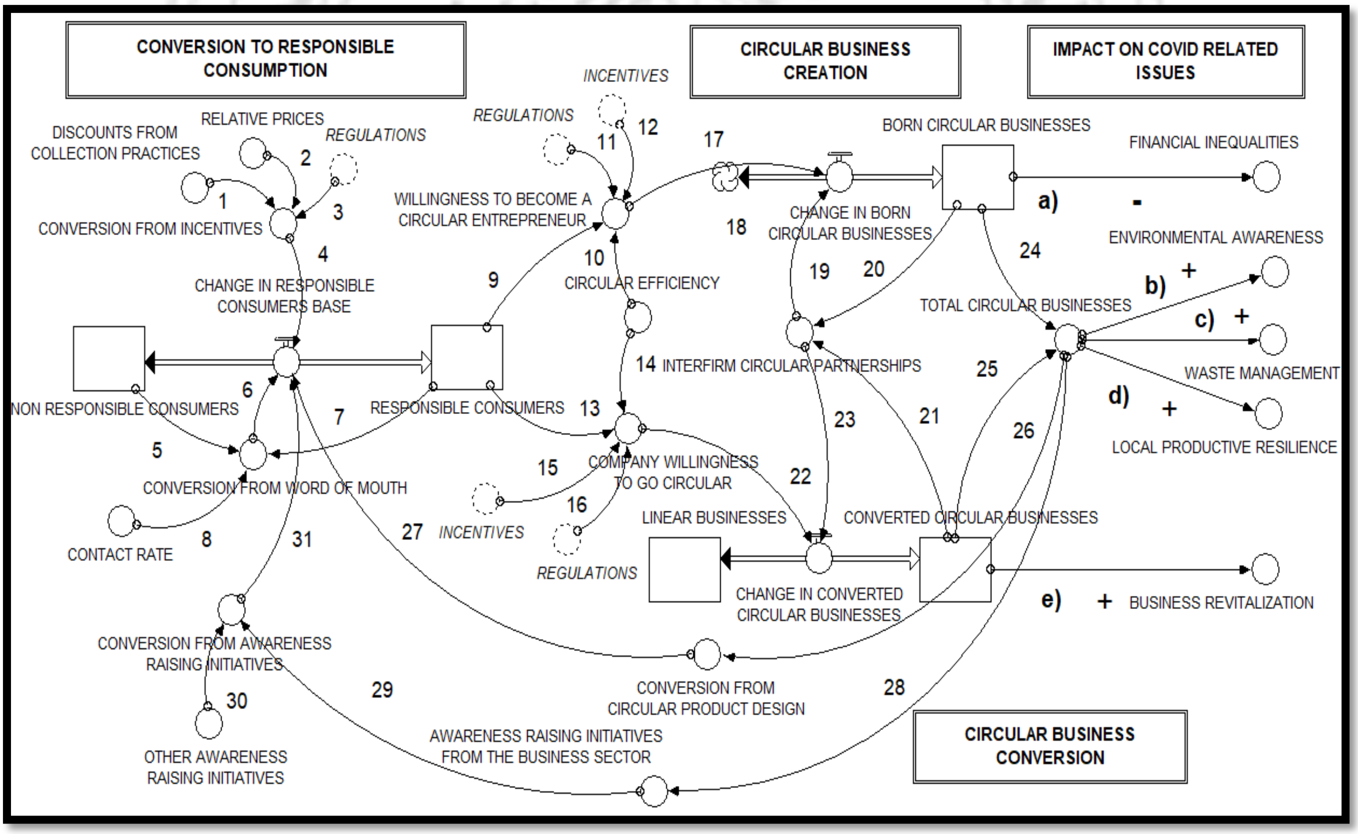
the diagram is devoted to circular businesses and distinguishes two cases: the 'Circular business creation', taking place when the company starts up with a circular business model from its own origin; and the 'Circular business conversion', occurring whenever already existing companies decide to make investments to implement CE principles. On the right side, it is represented the 'Impact on COVID related issues': this part of the model infers on how circular business dynamics can help in alleviating some challenges deriving from the actual systemic crisis. In order to favor the model intelligibility, all the links connecting the variables are numbered, except for the ones pertaining to the 'Impact on COVID related issues', emphasized with letters.

The following paragraphs provide detailed descriptions of the model areas and their connections. For explanatory reasons 'Circular business creation' and 'Circular business conversion' are addressed together.

Figure 2. Model's stock-and-flow diagram.



Source: Author's elaboration.

4.1.1 Circular business creation and conversion

The model recognizes the role played by entrepreneurial action in reducing environmental degradation and fostering sustainable development (Dean & McMullen, 2007). Three stocks within the model deal with circular business transitions. At first, it is made a distinction between 'Born circular businesses', starting to be circular from the beginning of their lifecycle, and 'Converted circular businesses', regarding previous linear businesses aiming to become circular. Crainer (2013) argues the need of businesses to reinvent themselves according to the promising Circular Economy perspective, by designing corporate strategies to metabolize waste in the economy.

To capture such shift, the stock of 'Converted circular businesses' is preceded by another, 'Linear businesses'. The connecting flow of 'Change in converted circular businesses' is affected by the 'Company willingness to go circular' (link 22) and by 'Interfirm circular partnerships' (link 23). This last variable is included since company partnerships are receiving growing attention for their ability to pursue shared sustainability and waste reduction goals (Veleva & Bodkin, 2018). In line with a shared value approach (Porter & Kramer, 2011), the variable helps to capture different kinds of collaborative processes helping the implementation of CE principles: born circular businesses-born circular businesses, converted circular businesses-converted circular businesses, converted circular businesses-born circular businesses.

The 'Company willingness to go circular' is affected by: 'Incentives' and 'Regulations' (links 15-16), the recovery of efficiency allowed by CE (variable 'Circular efficiency') and the stock 'Responsible consumers', representing the market demand for circular products and services. Thus the model portrays both business and contextual factors influencing the willingness of companies to transit towards a circular economy, such as the regulation activity of policymakers and international institutions (Centobelli et al., 2020).

Policymakers and governments' responsibility is due to the fact that they can act as both drivers or barriers for company CE transition, can remove existing barriers and support production and consumptions changes (Kirchherr et al., 2018), e.g. the EU Circular Economy Action Plan (European Commission, 2015), renovated with new limph at the beginning of Coronavirus crisis, presents interrelated regulatory packages "to establish a strong and coherent product policy framework that will make sustainable products, services and business models the norm" (European Commission, 2020, p. 3).

On the other side, CE is not just an environment respectful paradigm mitigating the externalities of human activities, but it encompasses (directly or indirectly) all the dimensions of sustainability. At business level, circular business models (CBMs) are a sub-category of sustainable business models (Bocken et al., 2016), which indeed target solutions for sustainable development through circular value chains and stakeholder incentive alignment. According to Geissdoerfer and colleagues (2018) the circularity of a business model, taking place whenever its constituting elements (value proposition, value creation and delivery, value capture; Richardson, 2008) go circular, allows the achievement of optimal sustainability performances. As argued by Esposito and others (2018), CE enriches sustainable paradigms by maximizing the product's lifecycle and converting unusable products in new sources of value in the same/differerent value chains (Centobelli et al, 2020).

Still, CBMs are invaluable sources of competitive advantage, promising to generate profits in a new and environmentally conscious way (Guldmann, 2016, p.7), for at least two reasons. First, by increasing product efficiency ('Circular efficiency' in the model) through the adoption of re-use, repair, refurbishment, and recycling practices for resource conservation and continuous circulation. According to a joint study of Ellen MacArthur Foundation and McKinsey, the circular transition can determine a 3% increase of Europe's resource productivity by 2030, generating cost savings of €600 billion a year and €1.8 trillion more in other economic benefits (Ellen MacArthur Foundation & McKinsey, 2015). Such figure means that industries are not taking the economic opportunities that Circular Economy can disclose. The second reason is that incorporating enviromental and social values in products, they result to be differentiated and non-commodified (D'Aveni, 2010) in the eyes of an attentive consumer. Unfortunately, contemporary entrepreneurship education is still focused on linear business models (Neumeyer et al., 2020).

Referring to the stock of 'Born circular businesses', its accumulation is due to the flow 'Change in born circular businesses', which in turn is boosted by 'Willingness to become a circular entrepreneur' (link 17), and 'Interfirm circular partnerships' (link 19). The 'Willingness to become a circular entrepreneur' is influenced, again, by 'Incentives, 'Regulations', 'Circular efficiency' and 'Responsible consumers' (links 13-16). However, in this specific case the presence of a responsible consumption's base influences the new circular initiatives in two ways: it still represents a market demand to be satisfied by new entrepreneurship energies; and it also constitutes the 'entrepreneurial humus', a basin of personalities, stimuli and values from which circular entrepreneurial intentions emerge. In fact, it is reasonable that the wannabe-circular entrepreneurs are responsible consumers in first place. Recalling the above discourse about CE related competitive advantage, the circular entrepreneurship is a promising route either to empower economically fragile people in trying their hand at new start-ups; or to induce already existing entrepreneurs in low-income settings to develop innovative products with less price sensitive customer targets (Morris et al., 2020).

4.1.2 Conversion to responsible consumption

The CE application is not a "quick win but a long-term undertaking" (Kirchherr et al., 2017, p. 228), requiring awareness of its socioeconomic implications and key implementation barriers (De Jesus & Mendonça, 2018), among which it was highlighted the "lacking consumer interest and awareness" (Kirchherr et al., 2018). For this reason, the stock-and-flow diagram shows changes occurring in consumers, who move from the stock of 'Non responsible consumers' to the one of 'Responsible consumers'. The responsible consumer is not just a person deciding to buy circular products and services, but he/she is also involved in CE practices, such as extending the use of products as long as possible to delay waste production, collecting goods to be recycled, sensitizing other people to the importance of circular consumption.

The idea is not just to look at consumers as recipients of green marketing campaigns aimed at aligning environmental benefits with consumer self-interest and subsequent purchasing (Grimmer & Woolley, 2012), but to adopt a "design for sustainable behaviour" view (Chamberlin & Boks, 2018), focusing on individual behaviors as resulting from several motivating factors simultaneously (Bocken, 2017).

Thus, the flow of 'Change in responsible consumer base' is movimented by various influences. First, the 'Conversion from incentives' (link 4), showing the impact of extrinsic motivations on circular practices. This variable in turn results from the combined effect of: 'Discounts from the collection practices' (link 1), taking place for example when old clothes are brought to public/private second-hand circuits or to clothing shops; 'Relative prices' (link 2), considering the price ratio between circular and non-circular products; and 'Regulations' (link 3), e.g. municipal obligations to separate waste collection, envisaging fees/fines for the non-collectors. The importance of consumer empowerment in CE transition has been recently acknowledged by policymakers (European Commission, 2020, p. 5), and also in the scientific debate the attention starts not to be devoted just to cleaner manufacturing, but also on strategies to educate consumers, to design eco-labels and to induce responsible consumption choices (Matthias et al., 2016).

Another factor stimulating responsible consumption is the 'Conversion from word of mouth', that could be a driving force for comsumption habits' switch in two ways: by spreading information about circular product quality, and by transmitting the awareness about the importance to practice CE principles. This variable depends on the contacts among non responsible and responsible consumers (links 5 and 7) and by their contact rate (link 8).

Other influences on circular consumption strictly derive from the business sector. Specifically, the 'Total circular businesses' inherently boost their own demand by proposing new circular standards of products and services ('Conversion from circular product design') and by promoting 'Awareness raising initiatives' (links 28-29). The latter, together with other initiatives coming from the public and third sectors (link 30) are aimed at educating people about circular economy concepts (Sharma, 2020). These links were included to acknowledge literature insights describing the calls for companies's good practices with consumers (in quality of downstream stakeholders) to improve their awareness and engagement, and to sensitize purchase decisions (Centobelli et al. 2020, p. 1744). Actually, limited customer knowledge of circular opportunities can slow the CE transition, given the consumers' familiarity with linear models and expectations of products and services based on it; then it is crucial to communicate with consumers and to convince them of CE benefits (Guldmann, 2016, p. 51).

As far as 'Conversion from circular product design' is concerned, it is worth noticing that the CE narrative, based on product/industry macro-loops such as product-life extension, redistribution and reuse, remanufacturing, recycling (Urbinati et al., 2017) is not just a company matter. In fact, product design practices, e.g. design for recycling, design for remanufacturing and reuse, design for disassembly (Mayyas, et al., 2012), as well as practices of product return or subscription to product service systems, where companies maintain the ownership of goods and consumer pay for their use (Tukker, 2013), are pivotal to both product engineering, commercialization to final customers (Urbinati et al., 2017) and ultimately for CE principles put in practice (Moreno et al., 2016). They act on channeling and educating responsible consumption behaviours, not just at the purchasing but also at the use phase (Bocken, 2017), and require companies-consumers close collaboration (Mendoza et al., 2017).

4.1.3 Impact on COVID related issues

Considering shifts to CE that may occur in the production and consumption spheres, it is possible to hint some wishful impacts on economic, social and environmental issues/challenges generated by the COVID crisis. Five arrows denoted by letters link circular businesses with selected challenges deriving from the pandemic. In two cases the link starts from a specific stock (respectively 'Born circular businesses' and 'Converted circular businesses'); in the other cases the positive impacts of circular business are not ascribable to certain processes of business creation/conversion and thus are modelled as descending from the 'Total circular businesses' in general terms.

The Coronavirus economic turbolence hit all industry sectors and many entrepreneurial ventures struggle to survive, while social disparities are exacerbated and financial conditions of weak social groups result worsened, limiting entrepreneurship and self-entrepreurship diversity (Neumeyer et al., 2020, p. 2).

In the stock-and-flow structure, link a) relating 'Born circular businesses' and COVID issues, expresses the concept that the start-up of circular initiatives can be a mean for the empowerment of low-income people and the reduction of 'Financial inequalitities' in society; whilst link e) to 'Business revitalization' represents the opportunity disclosed by the CE paradigm for the relaunch of pre-existing businesses hit by the systemic crisis.

In this regard, the implementation of CE principles at business level could be a source of competitive advantage for its connaturated efficiency recovery (Ellen MacArthur Foundation & McKinsey, 2015), its capacity to intercept less price sensitive customer targets (Morris et al., 2020), and its perspective opportunity to educate more and more people to the principles of responsible consumption (Matthias et al., 2016; Centobelli et al., 2020). In any case, the need for new products and services strictly related to the current safety concerns (e.g. single-use gloves and masks) and the demand of medical devices market, expected to grow by over 10% a year between 2020 and 2025 (Blériot, 2020), create new entrepreneurial spaces (Neumeyer et al., 2020).

The auxiliary variable 'Total circular businesses', resulting from the sum of the stocks of born circular and converted circular businesses, is connected with three impact variables:

→ 'Environmental awareness' (link b): the diffusion of circular business, with its educational and environmental consciousness, may contribute to respond to the Coronavirus-driven call to preserve the environment as a precondition for public health (Wuyts et al., 2020, p. 2);

→ 'Waste management' (link c): the circular entrepreneurship transition can actively contribute to address the waste management challenges imposed by Coronavirus (Neumeyer et al., 2020). In fact, beside the temporary pollution's decrease due to lockdowns, other dynamics are rising the waste production and greenhouse emissions all over the world. Sarkis and colleagues' concern (2020, p. 3) looks at environmental evolutions once production and transportation will return to pre-COVID levels. Actually, without appropriate measures, the environmental situation in the post-COVID era will be even worse than before (Climate Action Tracker, 2020). Indeed, the crisis caused a significant increase in waste production both in the medical (Wuyts et al., 2020) and non medical sectors, and a decrease in separate solid waste collection and recycling practices (Ragazzi et al., 2020). The environmental problem also concerns the dispersion of single-use masks, the increased plastic waste generation due to a new reliance on plastic-packaged food and the use of disposable utensils in the fear of virus transmission (Vanapalli et al., 2020).

→ 'Local productive resilience' (link d): in the early phase of spreading, the pandemic has caused a generalized deceleration/close of economic activities and international trading. In this context, the crisis has disclosed the fragility of many global supply chains, included the medical equipment one (Ranney et al., 2020). Even though in later stages of COVID diffusion the movements of people and goods have been restored, these dynamics led to questioning the "overreliance on just-in-time and lean delivery systems" (Sarkis et al., 2020, p. 2), showing the need for more resilient supplies at a local level (Blériot, 2020). Thus, CE transition becomes almost an imperative route to improve local resilience by building more localized supply, production and consumption systems (Sarkis et al., 2020, p. 2). Looking at the medical sector as a first illustration, it is possible to learn important lessons about the elasticity of bottom-up initiatives by private companies and individual citizens (e.g. production of sanitizing liquid and masks) to recycle locally available resources, thereby reducing the dependency from importations (Wuyts et al., 2020).

4.2 Causal loop diagram

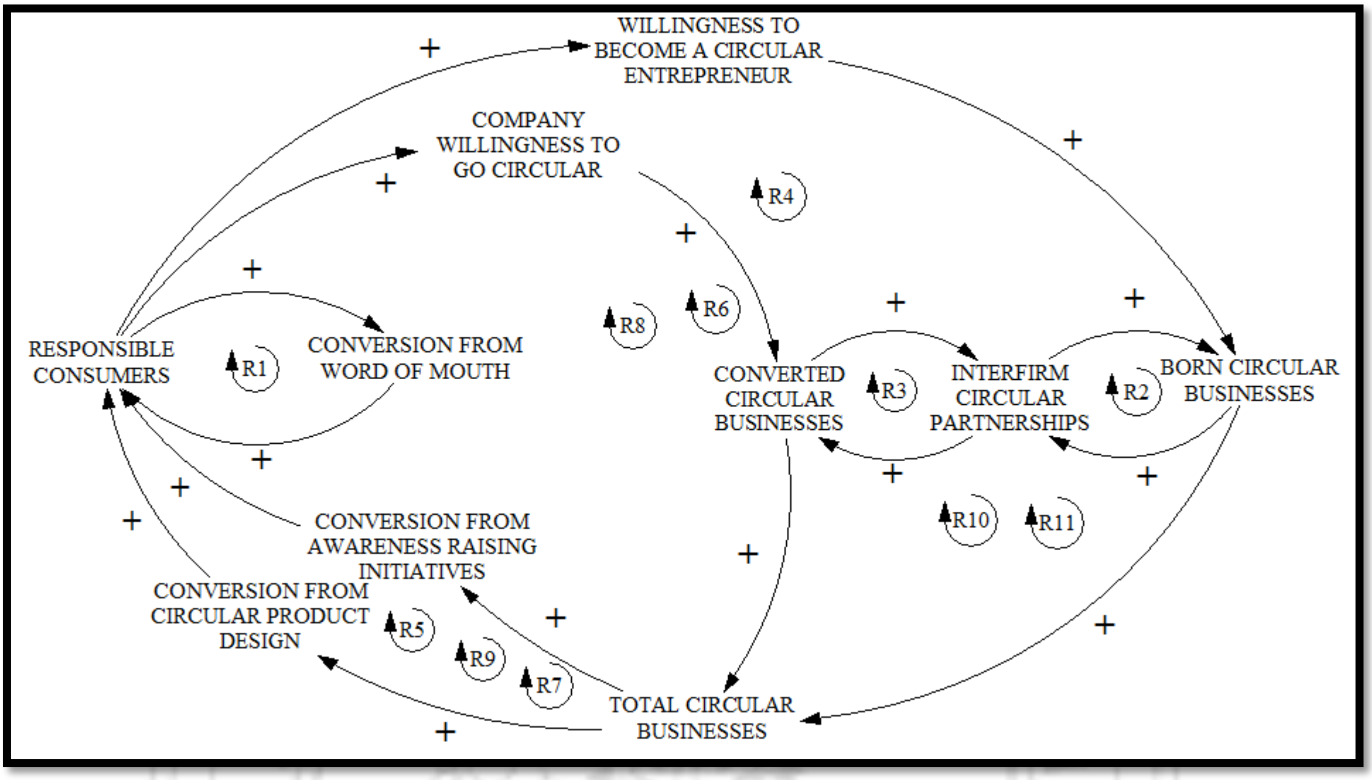
The causal structure hypothesized for the relevant system is based on complex chains of relations among variables, generating loops of different length and complexity. Then the stock-and-flow diagram presented above was synthesized in the CLD in Figure 3, made of 11 interacting feedback loops. Since each loop cointains just positive links, all the loops are reinforcing and distinguished from each other with a number following the R notation. The internal composition of each loop is reported in Table 1 below. As noticeable, loops R1-R3 are made of two variables, whilst the others are made of five (loops R4, R5, R8, R9) or seven variables (R6, R7, R10, R11).

Loop R1 describes responsible consumers' self-reinforcing dynamics due to word-of-mouth, Loop R2 illustrates the mutual reinforce of circular start-ups and interfirm partnerships: ceteris paribus, more 'Born circular businesses' will increase the opportunities of 'Interfirm circular partnerships', which in turn will stimulate new business creation through the spreading of examples, ideas, standard and opportunities. Similar structure in Loop 3, with the difference that the links are between 'Interfirm circular partnerships' and 'Converted circular businesses'.

The remainder loops show how responsible consumption and circular start-ups can influence each other according to different chains of causality, which take into separate consideration the effects of circular product design and awareness raising initiatives, as well as the impact of responsible consumers' enlargement, respectively on circular business creation and conversion. In Loop R4 a rise in 'Responsible consumer' has a boosting effect on the 'Willingness to become a circular entrepreneur' and thus on 'Born circular businesses' and 'Total circular businesses'. With the increase of circular businesses, also 'Conversion from circular product design' will be stimulated, thus increasing the stock of 'Responsible consumers'.

A similar circuit is contained in loop R5, with the trait that in this case the consumers' learning process takes place by mean of awareness raising initiatives. Loop R6 has a more complex chain: rising 'Responsible consumer' will induce circular business start-ups, forging more interfirm partnerships able to boost linear business conversions. This fact will result in the total amount of circular businesses, thereby enhancing consumers 'Conversion from awareness raising initiatives'.

Figure 3. Model's Causal loop diagram



Source: Author's elaboration.

Loop R7 repeats the R6's structure but considers the separate effect of 'Conversion from circular product design'. Loops R8 and R9 describe the responsible consumption and circular conversion's reciprocal stimulus, trained respectively by 'Conversion from awareness raising initiatives' and 'Conversion from circular product design'. Loops R10 and R11 portray other reinforcing dynamics: more 'Responsible consumers' will push the 'Company willingness to go circular' and then the 'Converted circular businesses', which will rise 'Interfirm circular partnerships' and, by this way, 'Born circular businesses' and 'Total circular businesses'. The latter feed back into responsible consumption, respectively through the influence of awareness raising initiatives (R10) and the circular product design (R11).

Loop groups R2-R3, R6-R7 and R10-R11 contain as a driving force the variable 'Interfirm circular partnerships', whose connotation is actually different in each couple: in the minor loops R2-R3 there are portrayed the separate effects of partnerships among homogeneous businesses: born circular in loop R2 and converted circular businesses in loop R3. In all the other cases the partnerships mix born and converted circular businesses. Specifically, loops R6-R7 show how born circular businesses participating into circular partnerships contribute to the conversion of linear businesses stimulating their circular innovation, whilst loops R10-R11 illustrate the value added by 'Converted circular businesses' to the 'Interfirm circular partnerships' and their inspiring effect on 'Born circular businesses'.

Table 1. Model's loops internal composition

LOOP	VARIABLES
R1.	Responsible consumer → Conversion from word of mouth
R2.	Born circular businesses → Interfirm circular partnerships
R3.	Converted circular businesses → Interfirm circular partnerships
R4.	Responsible consumer → Willingness to become a circular entrepreneur → Born circular businesses → Total circular businesses → Conversion from awareness raising initiatives
R5.	Responsible consumer → Willingness to become a circular entrepreneur → Born circular businesses → Total circular businesses → Conversion from circular product design
R6.	Responsible consumer → Willingness to become a circular entrepreneur → Born circular businesses → Interfirm circular partnerships → Converted circular businesses → Total circular businesses → Conversion from awareness raising initiatives
R7.	Responsible consumer → Willingness to become a circular entrepreneur → Born circular businesses → Interfirm circular partnerships → Converted circular businesses → Total circular businesses → Conversion from circular product design
R8.	Responsible consumer → Company willingness to go circular → Converted circular businesses → Total circular businesses → Conversion from awareness raising initiatives
R9.	Responsible consumer → Company willingness to go circular → Converted circular businesses → Total circular businesses → Conversion from circular product design
R10.	Responsible consumer → Company willingness to go circular → Converted circular businesses → Interfirm circular partnerships → Born circular businesses → Total circular businesses → Conversion from awareness raising initiatives
R11.	Responsible consumer → Company willingness to go circular → Converted circular businesses → Interfirm circular partnerships → Born circular businesses → Total circular businesses → Conversion from circular product design

Source: Author's elaboration

5. Conclusion

Tackling the current pandemic as a "black swan" (e.g. Halliburton, 2020; Deloitte, 2020), i.e. an unprendictable event carrying a massive impact (Taleb, 2007), the post-COVID scenarios for policy making and socioeconomic development can be summarised by two antipodes. The first is to treat this occurrence as a "history accident", to be overpassed through stimulus packages restoring the pre-COVID, business-as-usual mode (Bleriot, 2020). In alternative, the pandemic may be considered as an opportunity to learn from the pitfalls and shortages being experienced, creating the conditions for systemic robustness and local supply resilience.

This work confirms how Circular Economy, already considered a catalyst for reaching sustainability goals (Geissdoerfer et al., 2018; Esposito et al., 2018) can be a promising paradigm to deal with Coronavirus related challenges, fostering virtuous development paths.

In detail, the study contributes to the recent strategic management debate about CE, by proposing a system dynamics insight model to describe the basic mechanisms of circular business creation and diffusion, and their potential impact on COVID issues. Building on literature inputs, the model brings the novely to combine businesses and consumers' perspectives together, postulating that the transition towards CE is a mirror process of "conversion" involving with specific features both actors. The resulting system-wide analysis completes and transcends the outputs of previous works on CE business applications, whose focus has been the separate analysis of these categories and the development of circular business models (Linder & Williander, 2017; Bocken et al., 2016). The research also recognizes the relevance of consumer's role, as well as the learning dynamics taking place in both consumers and companies (Matthias et al., 2016; Mendoza et al., 2017).

The model building was iterative and the first research output was a stock-and-flow diagram stating a complex hypothesis about the causal structure of CE diffusion and its potential in alleviating the current systemic crisis. Based on this, a comprehensive causal loop diagram synthesized self-reinforcing feedback mechanisms.

Making a distinction among "born circular" and "converted circular" businesses, the study has the merit to provide a holistic view about CE, integrating and inferring from multidisciplinary literature and emphasizing the interrelated key roles of circular entrepreneuship and consumption. According to the model, CE initiatives can be means to reduce financial inequalities and to revitalize existing firms through a recovery of efficiency (Bocken et al., 2016; Guldman, 2016), new opportunities to differentiate products (Morris et al., 2020), and the perspective to "educate" their own demand to the principles of responsible consumption (Matthias et al., 2016; Centobelli et al., 2020). In addition, the stock of circular businesses has a boosting effect on environmental awareness, improves waste management, and stimulates productive resilience at a local level.

Although created by baring in mind the COVID emergence, the model dynamics lay at a general level, and can be considered as valid insights to contribute to a more sustainable and circular economic system, less exposed to systemic risks. Specifically, a number of self-reinforcing dynamics are described and disclose the potential triggering of virtuous loops, such as the enlargement of the responsible consumers' stock due to word-of-mouth, circular product design and awareness raising initiatives, as well as the mutual stimuli of circular start-ups/conversions and interfirm partnerships.

In the end, the model illustrates the importance of stakeholders to accelerate companies' transition to circularity, highlighting both the importance of partnerships with other companies and consumers, together with the role of regulations and incentives. For the planning and implemention of effective interventions supporting CE applications, policymakers need in first place to be aware of circular business dynamics (Kirchherr et al., 2018) and their networking impact on public value (Milios, 2018). Thus, a holistic view appears necessary at both national and local level, in order to create an infrastructural tissue favoring CE, with public/public-private agencies capable to intercept (and properly manage) funds and skills devoted to circular business development, interfirms partneships and sensitization campaigns.

However the study presents a series of limitations. First, the underlying literature was retrieved through Google Scholar engine, chosen for its multidisciplinarity and attitude to also include relevant non-scientific literature dealing with a novel and contemporaneous research topic. However, some publishers are not indexed in the database and citation data are over-estimated (Mikki, 200; Shultz, 2007). Future research could furtherly validate and enlarge this work by performing new literature rounds on other databases, such as WoS or Scopus.

Furthermore, the proposed model is not tailored to a specific sector or business case, and does not concern neither functional aspects (organizational, technical and operational features related to the development of circular products/processes), nor sociocultural and technological factors (e.g. the effect of digital technologies on CE transition).

The representation of circular business creation and conversion processes just refers to net rates of change in businesses' stocks (bi-flows). This is a simplification not capturing circular business closures or "returns to linear", as well as the factors affecting them. Moreover, the circular business conversion does not consider the process graduality of circular business model testing. Even the concept of circular efficiency, treated as an exogenous variable in the model, may disclose more complex dynamics of company experimental strategies, learning by doing processes and skill formation.

Thus, later studies could tailor the model to address sector-specific dynamics or identified business case studies, also considering the mentioned aspects not covered by the present research. So far, the impact variables refererred to COVID issues are exogenous, i.e. they do not feed back to other parts of the model and just receive impulses from it.

Next model advancements could enclose more variables and bidirectional relationships in this sphere, in pace with a better understanding of the socioeconomic and environmental implications of the pandemic.

Finally, the qualitative approach of this research calls for more investigations to test the model (or future versions of it) in the real world.

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European Journal of Social Impact and Circular Economy

http://www.ojs.unito.it/index.php/ejsice/index

Manufacturing Resilience during the Coronavirus Pandemic: On the investigation of Manufacturing Processes Agility

Panagiotis Stavropoulos[1*], Alexios Papacharalampopoulos[1], Konstantinos Tzimanis[1], Andreas Lianos[1]

[1] Laboratory for Manufacturinng Systems and Automation (LMS), Department of Mechanical Engineering and Aeronautics, University of Patras, 26504, Patras, Greece.

*Corresponding Author: pstavr@lms.mech.upatras.gr

Received: 06/09/2020
Revised: 15/11/2020
Accepted for publication: 04/12/2020
Published: 18/12/2020

Abstract

The unprecedented events that worldwide population experienced during year 2020 due to the COVID-19 pandemic, resulted in the formation of numerous challenges across the majority of aspects of every day life. Manufacturing industries and supply chain networks faced a unique decostruction during this period due to restrictions created by global or local lockdowns. Reduction of human resources availability and transportation restrictions linked with the extreme and rapid increase of demand for medical supplies led manufactring related activities to reach their limits. Moreover, the non flexible manufacturing methods that are employed for the production of this type of equipment as well as the delayed delivery of products that are used as raw material at the early production stages, resulted in market shortage of medical supplies while demand constantly growing. As a matter of fact, various production models and manufacturing processes had to be used at different phases, due to different levels of resilience. Automotive industry in particular tested corresponding processes' agility by transforming production and speeding up the production of medical equipment with alternative ways. However, the formal identification of the problem as well as the quantified requirements of each manufacturing method have to be evaluated in order to extract meaningful results that identify the reasons why traditional manufacturing facilities faced such difficulties in the production of medical equipment and to propose a roadmap where Additive Manufacturing methods can be used for the immediate, local and low volume production of the desired

product, giving time to non flexible industries, such as Injection Molding, to initiate the mass production. To assess the presented methodology, a comparison between two different manufacturing methods for the production of a respiratory component has been used as case study. Finally, a hybrid manufacturing model is suggested.

Keywords: Manufacturing Process; Agility; COVID-19; Medical Equipment; Manufacturing Network

1 Introduction

To understand how the manufacturing paradigms have been utilized during the years and how they can be applied systematically for crises like the COVID-19 pandemic, first, the modern business model has to be determined. The modern business model points out that individual businesses are not capable to compete each other alone, leading to the development of industrial alliances *(Douglas, Cooper, 2000)*. In the meantime, the complexity of modern devices asks for cooperation between industries from different sectors while the guideline of European Union for Corporate Social Responsibility (CSR) leads industries to follow a social profile, by respecting the laws and the competition with other industries. The main goal is to follow the pulse of the society in order to going side by side with the customer needs and finally raising their profit (*Corporate Social Responsibility & Responsible Business Conduct,2020), (Yildiz, 2014)*. By following this directive, as well as the need for humanitarian engineering and in particular response to emergencies (*Papacharalampopoulos et al, 2020),(Tayler,2016),* industries have been been been organized to consortia in order provide the required products while supporting each other. In this critical period the networks of business relationships and the willingness of individuals to support their National Health System to fight the COVID-19 virus (*Fauci et al,2020*), led to the creation of Hubs that work as supply chains in order to produce equipment which is under market shortage *(Carayannis, Zedtwitz,2005)*. Furthermore, it is highly desirable to address the concept of manufacturing resilience *(Gu et al, 2015)* through the manufacturing processes agility.

The absence of medical equipment can be explained considering that the developed countries, mainly the Western world, imports this equipment from countries which are located far away where the labor cost is low. Despite the fact that the transportation cost is high, the excessive profits seem to counteract these costs. The high delivery time and the increased domestic demand for medical supplies, followed by the local lockdown, resulted in increased demand in countries with many cases, leading to worldwide shortages *(Shokrani,2020)*. Decentralized production structures and AM Hubs tried to face this situation by adding flexibility to manufacturing processes in order to reflect local customer demand, by increasing the sustainability due to less distance that a product has to travel until the final destination, providing lower logistics, lower costs and shorter delivery time. From the beginning of this crisis it was evident that decentralized production structures have to be supported *(Shokrani,2020)*. In addition, the investments in education, learning & teaching factories, as well as the Industrial Research and Development played a significant role in the fight against this disease; without R&D and commercialization of AM as well as the domestic and small scale production, the situation would be worse. On the other hand, hubs took advantage of commercial platforms in order to provide details and knowledge to inexperienced people and hobbyists that possess AM devices. To this end, everyone could learn how to produce the required equipment following the product specifactions. Furthermore, reverse engineering and 3D scanners deployed to copy the different designs of the various equipment. In some cases, such as CPAP devices, the complex design asks for innovative and flexible solutions from the industrial world in order to develop an exact copy of the part *(Odena,Valls, 2020)*. In the meantime, chemical and pharmaceutical industry is really having a sprint in order to achieve some sort of attack to the virus with some sort of mechanism *(Panoutsopoulos, 2020)*.

The several manufacturing processes is a result of the technological improvements of the modern world, leading to different methods for making the same product (Florusse, 1992). Based on the material and the production volume target the suitable manufacturing processes may vary. For every manufacturing process a different infrastructure is needed (Chryssolouris,2006). AM on the other side, is a non-conventional manufacturing process which is able to cover small production volume with small production rates. However, it is able to adapt in different applications without excessive preparation time and labor cost *(Bikas, Stavropoulos, 2016)*. Numerous AM printing methods are available. They are categorized based on the printing mechanism and the printing material. The application, the user experience and the needed investment, are parameters that define which of the available machines is more suitable in every case *(Bikas et al, 2016), (Stavropoulos, Foteinopoulos 2018)*. Currently, several models and studies have been developed in order to simulate the AM processes and predict the product quality *(Stavropoulos, Foteinopoulos 2018),* the Build Time *(Komineas et al,2018)* and the consumed energy *(Peng, 2016*) while optimum sets of process parameters are available for different materials and printers *(Edwards, 2003), (Cantrell,2017)*. The above-mentioned work aims to make the AM processes predictable in terms of performance while the non-experienced users are able to create the desired product without being anxious for the selection of process parameters.

Apart from the utilization of AM in automotive, aircraft, aerospace and consumer product industry,etc., AM has been applied also in medical industry in different fields such as dental use, prosthetic arms development *(Mohd, 2018),* integrated human tissues in prosthetic members etc *(Partee, 2006)*. During COVID 19, AM has been involved in the production of Personal Protective Equipment (PPE), which is a number of parts that consist a set of medical protective equipment that can be used either multiple times or for one use and protect the population from getting in touch with diseased people and breath polluted air as well as in the production of breathing aids devices *(Haleem, Javaid, 2020).*

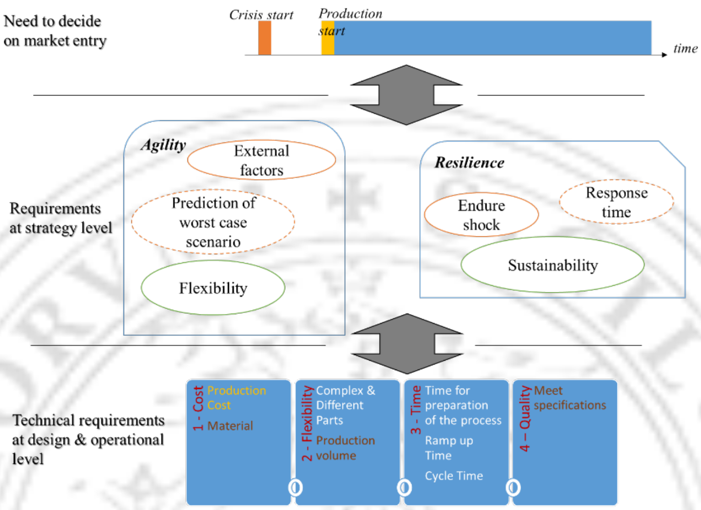
Due to the lack of the literature and the novelty of the effect of COVID-19 in every aspect of everyday life as well as in manufacturing processes, this paper aims to investigate corporate responses and case studies that have been adopted during this pandemic crisis as well as **to introduce an adaptive framework** that can be used in order to face similar crisis, quantifying the response-related capabilities of manufacturing processes. The structure of the paper follows the investigation of the facts that took place during the pandemic crisis, in chronological order. In Section 2, the methodology of this work is mentioned while in Section 3, the phenomenology of the factors affecting the demand is presented. In Section 4, the Personal Protective Equipment for the hospital staff is documented along with the devices in market shortage during COVID-19 pandemic outbreak as well as the contribution of industrial world in the production of the aforementioned equipment is mentioned. The capabilities of the traditional manufacturing methods for the production of the abovementioned clothing and devices are described in a more systematic and quantified way in Section 5. In the same section, the presentation of the formation of Glocal hubs and their activities can be found. A **roadmap is then sugested** therein based on the KPIs of production that are relevant to manufacturing resilience and manufacturing processes agility. The relationship between the production rate and the required time for the production of a medical equipment with a flexible, a non-flexible manufacturing and a hybrid method in order to cover the local and global demand is mentioned in Section 6.

2 Methodology

This work aims to access the traditional manufacturing methods for the production of plastic/metal medical supplies in terms of flexibility/requirements and to understand what were the reasons that led to shortage of medical supplies and Personal Protective Equipment (PPE). To achieve that, different sources of information have been considered in order to gather the necessary material and understand the chronological sequence of events related to pandemic outbreak as well as to find out what kind of medical supplies and protective equipment are needed to face this crisis. Moreover, there were lot of articles, indicating the contribution of the industrial world to that effort. From all the industrial world, automotive industries stood out because they were organized quickly and they speeded up the production of medical supplies such as (breath aid devices, surgery masks etc.) that were given to local hospitals in order to face urgent cases. At the same time, individuals and hobbyist were also organized to create medical supplies with low production volume, but with less transportation cost and delivery time. Later on, many more industries begun the production of medical equipment, taking as granted the proper design of the final product. Having gathered and studied the aforementioned information, it is crucial to investigate the working principles of traditional manufacturing methods that were capable to undertake the production of such equipment and divide them according to their characteristics, on flexible and non-flexible manufacturing processes. This division determines how easily they can adopt to the production of different products and production volumes. To do that, data from literature was used and analyzed.

The analysis of the obtained information and the better understanding of manufacturing hubs led us to define the Glocal Hub Manufacturing model that is capable to merge the high volume production of industrial world with the low volume production of individuals and restructured distribution networks in order to match the demand in medical supplies, locally and worldwide. The principles of this model and how exactly it works, can be seen on the related section (Section 5.1). To this end, it is evident that the developed hybrid manufacturing model needs to be agile and flexible to provide with the desired products under variable production volume and time. The resilience of the hybrid manufacturing model can be defined as the ability to withstand and counteract disruptions and after a number of steps to recover to the normal conditions. This system can be flexible and one of the main features can be the workload reallocation that depends on the availability of raw material and machines (*Xi et al, 2015*). The next important feature of the proposed hybrid manufacturing model is the agility of the involved processes. Agility is the capability to respond effectively to the requirements of the existing market demand. As an example, to reduce the process cycle time and increase the productivity rate as well as to produce a different design of a product without excessive preparation time (*Bessant et al, 2000*). All these factors could be integrated into a methodology of assemblying the proper criteria and interpreting them them into technical specifications (*Figure 1)*. The matching of the various KPIs can be considered a continuation of previous works on KPIs interlink for decision making (Papacharalampopoulos et al, 2020).

Figure 1: Agility and Resilience in Manufacturing Processes, integrating definitions



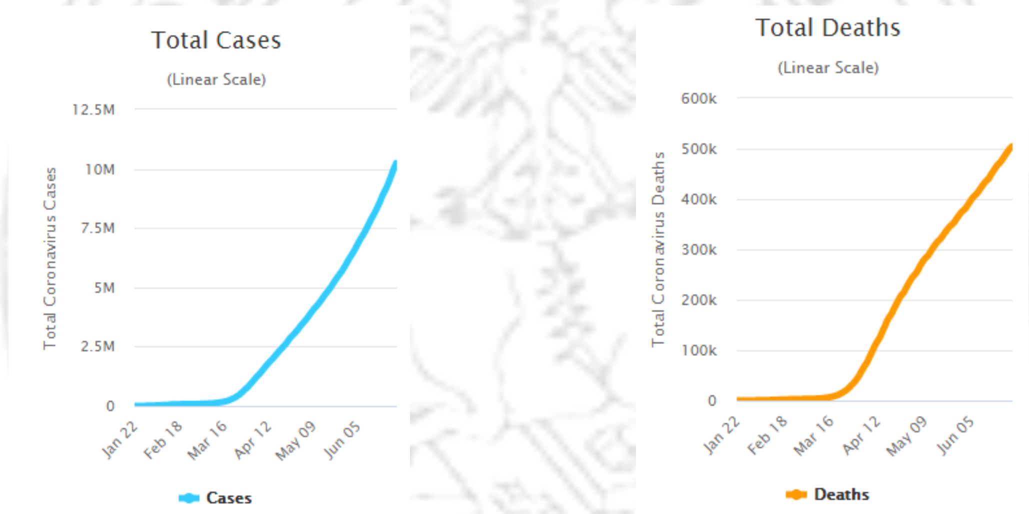
Source: [Fayezi et al, 2017],[Ahern, 2011]

As it can be observed from this methodology, the present work can be seen as an adaptive framework which can be employed in similar crisis were shortage of an equipment exists.The presented methodology refers to this unique occasion of Covid-19 pandemic crisis. Each occasion is governed from different characteristics that have to be studied and evaluated in order to extract a reaction plan, through a roadmap. The technical specifications have been set so far, through adoption of criteria, either on/off, denoted in brown font color in Figure 1 bottom schematic, or as desired, annotated in yelow colour and the ones that are of priority (white ones). To achive extracting a roadmap, however, the comparison of different manufacturing methods must be conducted (end of section 5.1), providing with details regarding the characteristics of each method as well as their capabilities. For the assessment of this framework, a respiratory component is used. The comparison between two separate manufacturing methods (Injection Molding and Additive Manufacturing) in terms of production volume and cycle time, proves that a hybrid solution is required along-side with the restructured distribution network with the aid of Glocal Hubs in order to face this difficult situation. In brief, Additive Manufacturing can provide parts at small production rate and volume until the mass production manufacturing methods reach the desired production rates.

3 Phenomenology of the factors affecting the demand-production equilibrium

The first confirmed cases of COVID-19 infections (due to virus SARS-CoV-2) appeared at the end of 2019. After a few months, this situation evolved into a pandemic with millions of diseased people, because of the existing socio-economic globalization where citizens from different countries communicate, work side by side, products are exported/imported and people are travelling across the world to meet new civilization and cultures. The worldwide spread of the virus created an medical supply demand for which the medical suppliers were not prepared to cover, leaving hospital's needs for equipment unmet. **Errore. L'origine riferimento non è stata trovata.**a represents the total confirmed cases over time while the **Errore. L'origine riferimento non è stata trovata.**b shows the number of deaths caused at the same time.

Figure 2:(a) Number of cases, (b) Number of deaths

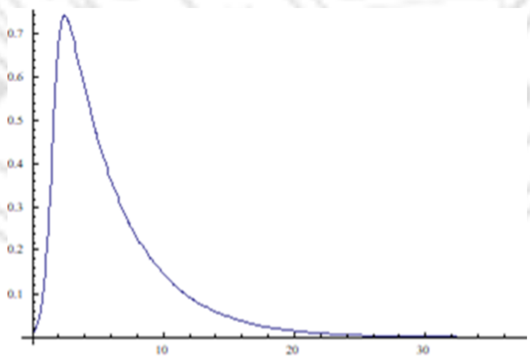


(a) (b)

Source: Covid-19 Coronavirus Pandemic,2020

The moment that confirmed cases raised rapidly is the exact same moment that the number of deaths increased accordingly. To face that situation, the medical suppliers had to increase the production in order to match the hospital demands. At hospitals, the infected people with severe symptoms, such as pneumonia (*Zu et al, 2020*), were under medical care with special equipment such as breathing aid devices, air control valves, etc. and the hospital staff was obliged to use continuously the Personal Protective Equipment and replace it in short time intervals, in order to protect themselves and prevent the virus spread *(Coronavirus disease (Covid-19) pandemic, 2020)*. Moreover, during this period the pre-arrenged medical meetings or surgeries were rescheduled in order to save medical supplies that can be used to fight the pandemic crisis, leading to death people with sever diseaces such as cancer (*Spinelli, Pelino, 2020*). To this end, the necessity for medical supplies mass production was intense and unpredictable while in most cases the suppliers could not quantify demands. In order to produce at a higher productivity rate, production line adjustments/optimization required. However, the medical suppliers had to cover the worldwide high demand, making of utmost importance the contribution of individuals, research center and industries, in medical equipment production. The following plot represents the infected percentage of population over time. It has been produced based on the equation of the SIR model *(Nesteruk, 2020)* and illustrates a bad scenario where even up to 70% of the population is infected rapidly. The vertical axis represents the percentage of population that has been infected for a certain time period while on the horizontal axis the time period, measured on days, can be seen. The evolution of this situation has indicated that measures such as social distancing had to be applied in order to avoid the virus spread. The abrupt increase of diseased suggests the need for handling a lot of cases at the same time. The provision of personal protective and hospital equipment are prerequisites for the curing of diseased people and the reduction of new infected cases. This procedure lasts over a long time period, until the curve is flattened which means that the virus spread has been minimized *(Haleem, Javaid, 2020)*(***Errore. L'origine riferimento non è stata trovata.***).

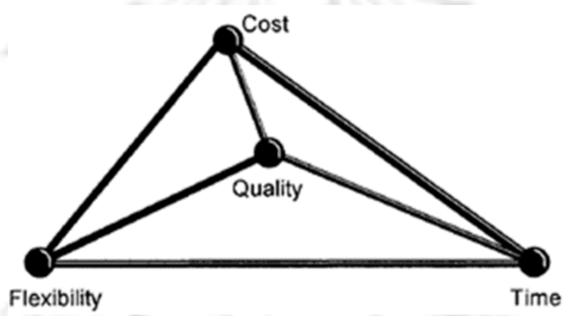
Figure 3: Infected percentage over time



Source: Haleem, Javaid, 2020

During the lockdown period, companies and industries were closed, the individuals were working from home while research centers were opened, following at the same time the protective measures. People with the necessary knowledge combined their forces to serve the national health system of their country, producing the required protective equipment and breathing aid devices (*Designs for Live-saving Breathing Aid to be Made Freely Available, 2020)*. Thus, with the aid of reverse engineering, the accurate design copies of several parts were available, while the final products were created by taking advantage of Additive Manufacturing techniques for plastic and metal printing. The domestic production and the small-scale production from research centers could not meet the raising demand so there was need for transformations in the production line of big factories e.g. automotive industry etc. According to Chryssolouris *(Chryssolouris, 2006),* there are four classes of manufacturing parameters to be considered when making manufacturing decisions: cost, time quality and flexibility. These decisions, depend on the particular problem, specific objectives, goals and criteria (***Errore. L'origine riferimento non è stata trovata.***).

Figure 4: The Manufacturing Tetrahedron



Source: Chryssolouris, 2006

Meanwhile, the situation had been getting worse. Therefore, the transformation of factories for medical supplies production had to be based on the flexibility of the production line, in order to create as soon as possible the first products to share to the hospitals. The products quality had to be fair enough to serve their cause while the productivity rate to be high to match the demand. The aim of the present work is to identify which of the existing manufacturing methods are enough flexible to deal with the sudden/unpredictable increase in demand, in medical supplies during COVID-19 outbreak. On the one hand AM has proven its potential, in small scale/domestic production, covering the local needs, while on the other hand, AM low productivity rates indicates that this manufacturing method is not capable to match the rising hospital demand, worldwide by producing in mass production medical supplies *(Kose, 2020), (Baumers, 2015).*

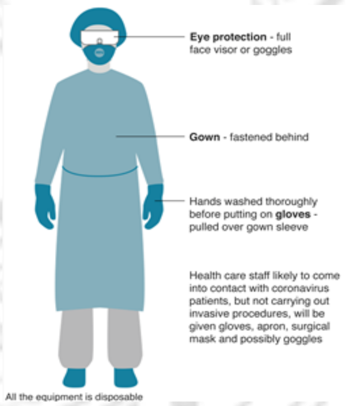
4 Paradigms of medical parts in high demand and the response of industry

Based on available evidence and medical surveys, the SARS-CoV-2, the virus that causes COVID-19, can be transmitted among the population either on close contact via hugs, handshakes and kisses or travel longer distances during talking, sneezing as well as coughing *(Nesteruk, Igor, 2020)*. The ease of virus spread has led to more than 2.4 million confirmed cases *(Covid-19 Coronavirus Pandemic,2020*) since today upsetting the scientific community, making at the same time the use of Personal Protective Equipment (PPE) of utmost importance for people that are obliged to work nearby diseased people such as nurses, doctors, hospital cleaners as well as ambulance staff (*Source:*). Due to the nature of the virus contagiousness, the equipment has to cover the whole body, mainly the free of clothes, skin. The table below (

Table *1*) presents the safety clothing that it is considered as Personal Protective Equipment from World Health Organization (WHO) (*Coronavirus disease (COVID-19) pandemic, 2020) , (Yao, 2020).*

Figure 5: (a), (b) Safety clothes and personal protective equipment (PPE)

(a)



(b)

Source: Personal Protective Equipment (PPE),2020

Table 1: Suggested equipment for human protection

Protection	Suggested equipment
1. Respiratory protection	Face mask or surgical mask: N95, FFP2, FFP3 or equivalent
2. Body protection	Gown/ apron: Long-sleeved water resistant
3. Hand Protection	Safety gloves
4. Eye protection	Goggles or face shields

Source: Authors elaboration

Apart from the wearing equipment the COVID-19 pandemic outbreak has brought to surface the importance of equipment that is used in severe respiratory diseases. Meanwhile, the treatment in hospitals is based on the proper operation of assisting breathing devices. On the one hand the common breathing devices, without mechanical support, work on affected people without severe symptoms while on the other hand the Continuous Positive Airway Pressure (CPAP) is form of non-invasive mechanical ventilation, working as breathing aid, which applies mild air pressure on a continuous basis and keeps the airways continuously open in patients who are able to breathe on their own, but they need help keeping their airway unobstructed (*Ti, 2020)*. In addition, air control valves are responsible to control the oxygen that fills in the breath mask from an external respirator *(Ball, 2011)*. Without these valves the patient mask is not capable to work. In general, the aspirators/ventilators were in demand due to high numbers of intubation occurrences. These machines are generally expensive (*Li, Xiao, 2020) (Elling, Politis, 1983)*, consist of many different materials and also require assembly further to processing, while the production rate is bounded, according to Stefan Dräger who is the head of a ventilator manufacturer (*Top German ventilator company warns on global supply crunch, 2020)*. However, they can be reused once a patient exits intensive care. Regarding the consumables, however, they can be used only once, and they may need change every five days on average. Also, customized solutions often had to be taken into consideration, as often come across in the media from a number of sources like the Brussels (AFP) hospital. The main difference in addressing manufacturing of such equipment is that masks can be manufactured in a distributed, home-made way, even though the demand is high (even 70% of the population may need them daily according to **Errore. L'origine riferimento non è stata trovata.** from NHS, while valves (*Figure 6b*) require machine tools and the demand occurs at bursts and is a bit lower, involving only the intubated patients *(Yao, 2020)*. The treatment also implied demand for continuous processes, like hospital-related gases, medicine, and disinfectants *(Ti, 2020)*. Furthermore, it is worth noting that applying circular ecomomy policies in this particular case may be hard or even unacceptable due to the protocols existing, and due to the fact that the virus has not been previously met by medical experts or authorities *(Chartier, 2014).*

Figure 6: Devices

(a) (b)

Sources: (a) CPAP Device (Designs for Live-saving Breathing Aid to be Made Freely Available, 2020), (b) Air control valve (3D CAD File: Respirator-free reanimation Venturi's valve, 2020)

4.1 Link to capabilities of existing lines

Although many industries have contributed to this fight, automotive industries are studied due to the fact that they take advantage of cutting-edge technologies which are used from skillful operators, as well as, flexible and non-flexible manufacturing processes and it is worth to see how they reacted in order to cover the demand of medical equipment that faced shortages. Apart from actual products, many industries circulated the 3D desing of a medical equipment(respiratory components) to individuals, in order to create the desired part with the appopriate quaility and under the requested specifications. Car manufacturers and other industries accompanied by the traditional suppliers of medical equipment have been organized in order to address the spike in demand by speeding and scaling up the existing production. The World Health Organization (WHO) has published a list of COVID-19 critical items facing global shortage such as gloves and masks (*Table 2*).

Table 2: Critical items that face global shortage

Category	Critical Items identified by WHO	Example of facilities that might be repurposed
Protective Person Equipment (PPE)	• Gloves, examination • Gloves, surgical • Goggles protective • Gown, protective • Face shield • Mask, particulate respirator • Mask, surgical	• Textile factories • Garment plants • Yarn spinning mills • Electronic assembly plants • Injection molding facilities • Prototyping shops (3D printing)

Diagnostic Equipment	• Lab screening test kit • Lab confirmation test kit • RT-PCR kit • Extraction kit • Cartridges for RT-PCR automatic systems • Swab and viral transport medium	• Pharmaceutical preparations • Biopharmaceutical preparations • Pilot biotech plants • Clinical research laboratories
Clinical care equipment	• Pulse oximeter • Concentrator of gas • Nasal Oxygen cannula, with prongs • Ventilator patient, for adult, pediatric • CPAP with tubing and patient interfaces for adult and pediatric • Suction pump, mechanical • High-flow nasal cannula (HFNC)	• Automotive production lines • Aerospace manufacturing plants • Specialized engineering service and testing facilities • Manufacturing technology and innovation centers • Vacuum cleaner assembly plants • Machine shops

Source: Authors elaboration

In modern manufacturing, production processes can be highly automated and specialized aiming to maximize the productivity rate. The approach of lean manufacturing tends to eliminate waste across the production line and improves productivity. Although a highly efficient and profitable production can be developed, it is extremely difficult to transform the production line to produce a new part. Several industries face difficulties to reach the desired level of quality and performance in short time after the initiation of a new production line. However, the attempts continued in order to tackle the further expansion of the disease by covering the needs in medical supplies, making possible to cure several cases by protecting the hospital staff, Most of the industries participating in the global effort mainly produce masks, respirators and head mounts for the face shields. The response of the automotive industry is analyzed indicatively below. During this period GROUP VAG was capable of producing face shields (350 units per day), automated ventilators (13 prototypes) , reusable respirators (60 per day), and surgical masks (1000 per day) while PSA and FCA groups were producing respirators (200 per day), visors (30 per day) and masks accordingly. The experienced manufacturers and industrial consortiums not only transformed their production line to create the required equipment but also, by working side by side with the traditional medical suppliers achieved to share their knowledge in how to improve their production rates. In some cases, industries lent equipment, mainly 3D Printers, to research centers in order to manufacture simple equipment for the protection of local hospital staff (*Table 3*).

Table 3: Car manufacturers contributions (Mapping the auto manufacturers building PPE and medical equipment to battle COVID-19, 2020)

Manufacturer	Product	Partner	Details
BMW	Ventilator parts	None	Utilization of the 3D printers
Ferrari	Ventilator parts	Siare Engineering	Supercar maker is preparing to manufacture parts at its factory
Fiat Chrysler	Ventilator parts/ Masks	Siare Engineering	-Siare notes that carmakers have more component purchasing power than it does. -Aiming to distribute to emergency workers and first responders initially.
Ford	Ventilators	GE Healthcare	Rawsonville previously made oil pumps, battery packs, induction systems, ignition coils and fuel pumps
General motors	Ventilators	Ventec life systems	Kokomo previously made electronic and semiconductors components
Jaguar Land Rover	Masks	N/A	Its own design utilizing its 3D printing capabilities
Linamar	Ventilator parts	O-Two Medical Technologies	Partnership between Linamar, Magna and Martinrea to provide parts for ventilator designs
Mahindra	Ventilators	Unnamed ventilator producer	Manufacturing face shields and working on developing a low-cost ventilator design that will cost less than 7.500$ per unit
Magna	Ventilator parts	O-Two Medical Technologies	Partnership between Linamar, Magna and Martinrea to provide parts for ventilator designs
Marelli Corporation	Ventilator parts	Siare Engineering	Discussions are being held to confirm whether Italian manufacturers will build parts themselves or increase Siare's capacity
Martinrea	Ventilator parts	O-Two Medical Technologies	Partnership between Linamar, Magna and Martinrea to provide parts for ventilator designs
McLaren	Ventilators	Consortium	Joined a UK consortium to develop an emergency ventilator for rapid deployment
Mercedes F1	CPAP devices	None	Developed and building a CPAP machine which could reduce the need for medical ventilators by keeping the patients out of intensive care
Nissan	Ventilators	Consortium	Joined a UK consortium to develop an emergency ventilator for rapid deployment
SEAT	Ventilators	Protofy XYZ and others	The design uses 3D printed gears and a repurposed windscreen wiper motor from the SEAT Leon and is made on the Leon subframe assembly
Tesla	Ventilators	Medtronic	Aiming to develop its own design using many parts repurposed from Tesla cars
Toyota	Masks Filters	None	Preparing to 3D print face masks for emergency personnel and preparing to produce filters for respirator and ventilator use.
Volkswagen	Ventilator parts	None	The company is looking to utilize its 125 industrial 3D printers to build ventilator parts

Source: Authors elaboration

The contribution of Additive Manufacturing in that effort seems to be of utmost importance due to the flexibility of the process which gives the possibility to everyone possessing a 3D printing machine to create/develop a part, without manufacturing experience. The solution of Injection Molding follows as the process which is ideal to produce a significant volume of products in specific time. That process also involves the development of molds and the machine set up, assuming the existence of the machine in a facility.

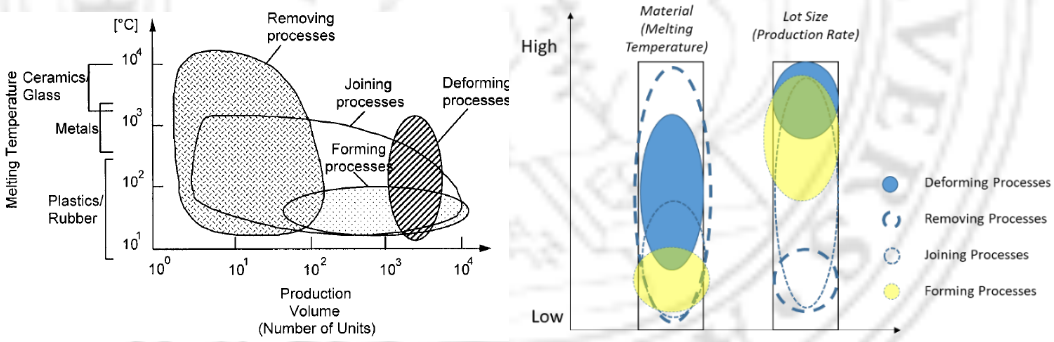
5 Capability & Agility of Manufacturing Processes and Manufacturing Resilience

5.1 Quantifying the Processes capabilities

The centralized mass production for medical supplies made from plastic takes advantage of the forming processes. In the industrial scale it is crucial to produce with high productivity rate, low cost, and fair product quality. Moreover, the production has to be flexible enough to produce a variety of products without wasting time and money to change the equipment every time that a new design comes to the production *(Chryssolouris, 2006)*. In

Figure 7 the recommended manufacturing processes for several materials can be seen, considering also the production volume and the melting temperature of the machined material. The estimated production volume for medical supplies like face shields, face masks etc. is identified between 10^2 and 10^6. Therefore, the forming processes seems to be the preferable for that kind of production. The diagram has also been reformed to an axes form, showing the two criteria independtly.

Figure 7: Manufacturing processes vs material



(a) *(b)*

Sources: (a) Original form of the diagram (Chryssolouris, 2006), (b) reformulated form of the diagram

According to Chryssolouris (Chryssolouris, 2006), forming processes are divided into casting and melting processes. The casting process involves the effect of gravity during the filling of the mold while the melting process takes advantage of applied pressure to process viscous polymers, at high temperatures, forcing the material to flow under the effect of gravity. For plastic material, the molding process correlates with melting processes, which takes place with the aid of a mold, similarly to casting process in metals. A wide range of molding processes can be found, namely; compression molding, transfer molding, injection molding, extrusion, reaction injection molding, rotational molding, calendering, and melt spinning. The characteristics of the forming processes are included on the table below (Table 4). In this study it is important to have bear in mind that non-dedicated for medical supplies factories have to be transformed in production lines with high production rate, fair quality to protect the medical staff and assist the diseased people as well as low labour cost. Assuming that the transformation is possibly to happen on industries with facilities to create the mould and then proceed to the injection molding for the production, the cost can be maintained on low levels for tooling, while the transformation period can be significant small.

Table 4: Forming process characteristics

	Cost	Production Rate	Quality	Flexibility
Forming Processes	High Tooling/Low Labor cost	High	Medium to Low	Low

Sources: Chryssolouris, 2006

The above-mentioned characteristics there are available for every process explaining the reason why industries decide to run the production with the aid of certain processes based on four main indicators:

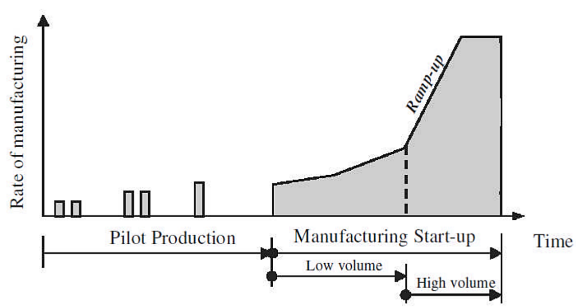
a. Material selection
b. Manufacturing of complex designs.
c. Time for the preparation of the process (molds, machine process parameters, etc.)
d. Production Rate
e. Ramp up rate

The meaning of the first three terms can be easily extracted. The material term refers to the choice that engineers have made to be used for a certain product based on its properties. The material choice is the first step for the development of a product and manufacturing process selection. Figure 8 shows preferable processes for the manufacturing of products based on their raw material. If the circumstances lead to change the raw material, then, all the production process has to change as well as the design of the product. So, there is a strong relationship between the product design and the raw material choice, explaining why the design is the second step of the process selection. The product design guides the manufacturing process. Complex parts spend too much time in manufacturing processes (one dedicated machine or more machines based on the manufacturing phases) while simple designs need significantly less time. Moreover, the part design defines the required equipment to run the process. As an example, for injection molding process male or female molds are required.

The complexity of molds design (*Italian engineers support the fight against the COVID-19 virus by 3D printing valves to medical equipment, 2020*) and manufacturing is considered as extra time added to the final production time. Up to this point it can be extracted that on the one hand, for small production volumes and for immediate initiation of production, processes that require complementary equipment to run should be avoided, while, on the other hand, the extra time spent at the early stages of production (mold manufacturing/design) is covered due to the increased production rates that a process, such as injection molding, can offer.

Production rate refers to the number of units produced over time. The production rate can be expressed, when the production run smoothly, and the machines are optimized. At an earlier stage, the production has been tested in several scenarios, in order to examine if there are issues that can lead to faulty products. So, three stages can be pointed; a) pilot production when the first parts come out of the production and both the machines and the parts are under inspection to ensure, that the products follow the product requirements and the machines are in good condition; b) the low volume phase where the production line work at 50% of its potentials in order to control the production in terms of energy consumption, cost as well as the wear of machines; c) the high volume phase where the product quality, production volume, energy consumption etc. are optimized and they remain constant over time *(Ball, 2011).* The last term ramp up expresses the rate with a production can address all the knowledge obtained during the low volume production in order to move to high volume production or from pilot production to low volume production. If the ramp up is low, then the production needs much time to alter from the one level to the other. The ramp up time as well as the different production phases can be seen below.

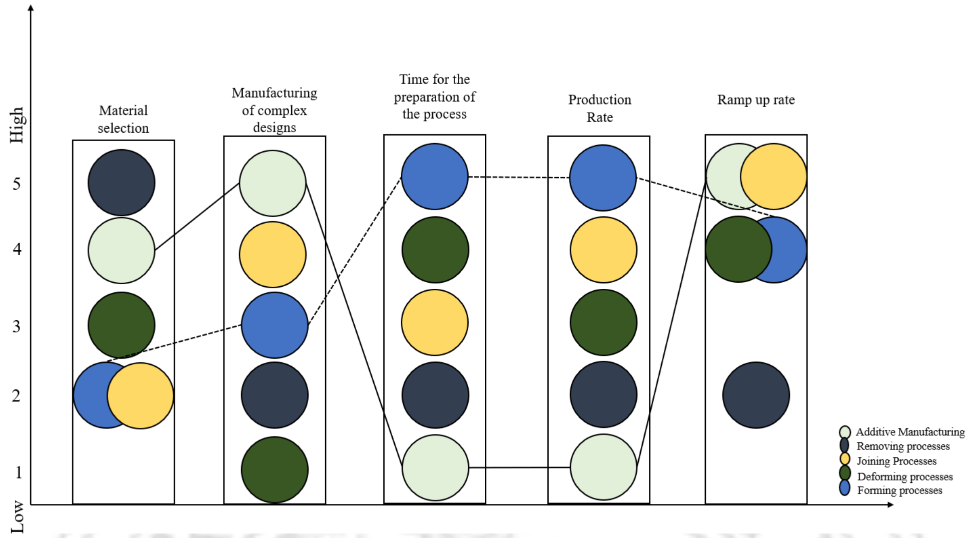
Figure 8: Production phases



Sources: Ball, 2011

Figure 9 aims to present how the five main process selection indicators affect each process. The scale 1(low)-5(high) defines the variety of different materials that can be processed on each process, the capability and agiility of processing complex designs, the required time for the preparation of each process and finally which one of the available processes can offer higher and lower production and ramp up rate. To this end, it can be said that this scale is a comparative means for the examined parameters. e.g. the ramp up rate for additive manufacturing processes can be equal to joining process and higher of removing process. This happens due to the process variables that are involved on the process; for removing processes, factors such as cutting fluid temperature and flow, cutting tool failures, workpiece placement on the table, process parameters selection etc. seems to reduce the ramp up rate, while in AM processes, less factors are involved such as process parameters selection and filament replacement after certain time intervals, leading to higher ramp up rate. A utility function derived from these five criteria could be defined, however, the current framework ought to take the five constituents separately into consideration, in terms of a five-dimension vector (or more formally like an array). This five-fold metric could be called as extended manufacturing process agility metric.

Figure 9: Process selection procedure (each component has a unique scale) utilizing extended process agility



Source: Authors elaboration

5.2 Considering Glocal Hubs Manufacturing as a manufacturing model for enhanced resilience

The Glocal Hub Manufacturing Model is defined as numerous locally placed manufacturing subsystems that act together in a unified network to cover a demand that appears at a global level *(Trappey, 2007)*. The Glocal Hub Manufacturing system shares similarities with the hub-and-spoke system the airlines use to better cover the travelling demands from minor origins and destinations and at the same time remain cost efficient *(Cook, 2014)*. With an opposite mentality, the initial approach to cover a large part demand was to subcontract the overall need to a single supplier and after the production of the total batches is completed, the orders are divided and shipped to the locations in need accordingly. When time response is critical and demand spikes can occur, this singular supplier system indicates high risks of bottlenecking and failure. The three main causes were identified to be:

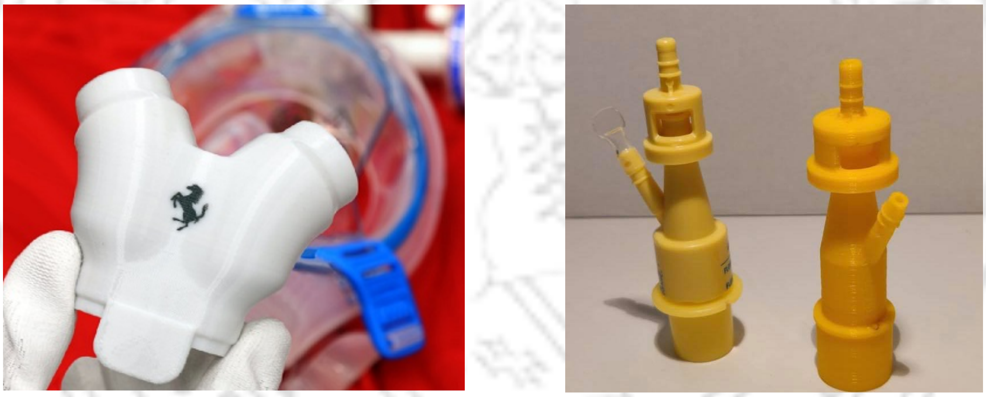
i). The singular supplier's production stops and requires additional troubleshooting actions and time to restart.

ii). The utilization and setup of additional manufacturing equipment for parallel production is cost intensive.

iii). The global shipping network is overloaded.

Implementing the Glocal Hub Manufacturing model for mass production compensates for the above risks of the singular supplier model. The large number of local manufactures, near the hub in the high supply need, secure that in the scenario of failure of a production line of one or more suppliers, the remaining functioning ones can intensify their production rates to supplement the failure or at least partially cover the supply demand. The ability to utilize additional equipment in a short time is process dependent. As an example, in the case of the respirators which faced excessive demand during COVID-19 pandemic, Additive Manufacturing machines were more efficient and flexible to set up the process and inititate the small scale production than Injection Molding machines. Finally, the organized Glocal Hubs cotributed to shorter traveling distance between the supply and demand which performed better in the case of a shipping network malfunction. The current circumstances regarding the COVID-19 outbreak created an absurd spike on the demand of medical devices *(Haleem, 2020)*. The identified medical components can be divided into two main categories; a) the ones that can be manufactured exclusively by a specific manufacturing process and b) those that with simple desing modifications can be manufactured via alternative ones (*Figure 10*, *Figure 11*).

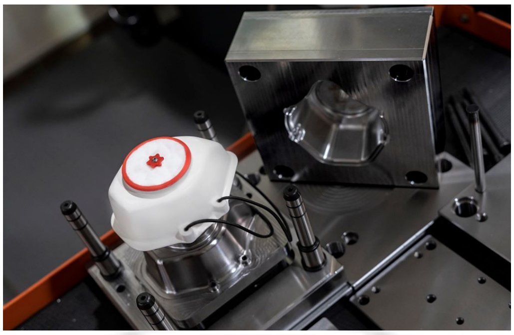
Figure 10: Examples of additive manufactured



(a) (b)

Sources: (a) Additive Manufactured valve for emergency masks to assist patients suffering from respiratory failure (Ferrari continues its efforts to fight the Covid-19 pandemic, 2020) ,[b] similar valve for oxygen respirator were an urge, the right one (Italian engineers support the fight against the COVID-19 virus by 3D printing valves to medical equipment, 2020)

Figure 11: Face mask mold, injection molding for mass production



Source: Edition 2020, 2020

When it comes to mass production of medical equipment, the production is centralized, and the supplying distribution is realized via the shipping network. That is, the uneven equipment demands across the globe, combined by the bottleneck of the supply network between Asia and Europe resulted in crucial deficiencies of medical equipment. A profound solution was given to this issue by the Additive Manufacturing community, from individuals with both professional and desktop equipment. The medical components that were on shortage and that had part features that where AM manufacturable *(Bikas, Lianos, 2019)* were rapidly reverse engineered and manufactured in large numbers from users that acted as suppliers with access to AM equipment. The demand was thus covered via the localized manufacturing hub model. The small batch of approximately 12 pieces per print was counteracted by the number of the available equipment spread across European countries. Only Greece has an active 3D Printing community for plastic manufacturing that is estimated to be of more than 2000 individuals with at least one AM machine each.

To understand the better suitability of AM in the case of the COVID-19 pandemic the medical equipment demand and supply chain must be investigated.

i). The first point was that the overall demand increased in a short period of time.

ii). The second aspect was that the overall large number of medical equipment produced were to be distributed in smaller numbers among the hospital units that were facing shortage. This step in the supply chain was bottlenecked from the shipping networks that were also facing profound numbers in regional and international level.

The AM supply chain was in the contrary locally identified and evenly spread due to the low cost of the AM plastic equipment. This made the shipping more efficient as the hospitals were supplied by close-by AM suppliers. This alternative way was also not dependent on a singular standalone large supplier but on a coherent network of the AM community of small but numerous professional and amateur individuals. This resulted to the satisfaction of the demand spike more efficiently with AM compared to the Injection Molding supply. The idea behind the decision making for the most suitable process is to provide; a) rapid response from the initial demand spike to the first manufactured part and b) high production rates to cover the global demand in time. The parameter of time is the most critical parameter in that decision making framework.

These two system characteristics are contradicting for a singular manufacturing process. As the mass production capacity and pace increase, the agility of the system decreases, whereas a highly agile system is not capable of mass production. To abide to both specifications a hybrid system it seems to be more functional. The first subsystem can manufacture rapidly and produce initial batches to feed the demand (AM). This buys time for the second system to reach high production levels and cover the overall demand (Injection Molding)

6 Workflow adaptation for the production of respiratory components

To investigate further the mechanism behind this unprecedented supply chain, the respiratory component was chosen as a case study (*Figure 10*). The Additive Manufacturing(AM) and Injection Molding(IM) productions are to be compared for the manufacturing performance. All the different process steps and their relative durations were identified for a new supplier to initiate production (*Table 5)*.

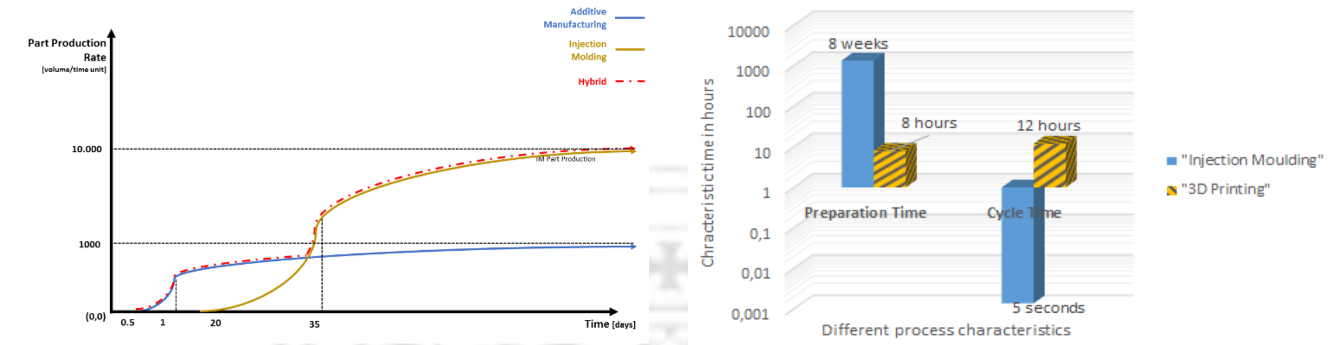
Table 5 AM and IM process steps comparison

Steps	Injection Molding	Additive Manufacturing
1	Part design for injection molding manufacturability	Part design for AM manufacturability
2	Mold design and manufacturing	Optimizing the process parameters
3	Optimizing the process parameters	Part manufacturing
4	Part manufacturing	

Source: Authors elaboration

In Figure 12, it can be seen that the AM response time for the initial part manufacturing is much shorter than the one for injection molding. This is due to the fact that the process steps from part design to the actual part manufacturing are fewer and shorter. The aforementioned quantities for the required time and production rate are an indicative average. The actual numbers are case dependent and can vary. That is, once the upstream steps are realized, the capacity and production of injection molding is far superior compared to AM.

Figure 12: (a) Compared process steps, (b) Comparing Injection Molding and 3D Printing: Preparation Time in IM concerns design of the mold, while in 3DP it concerns design of the part. based on authors estimation and literature



(a) (b)

Source: Guidance for wearing and removing personal protective equipment in healthcare settings for the care of patients with suspected or confirmed COVID-19, 2020

From Figure 12 the utility function that measures the success of the decision making for the appropriate manufacturing method can be obtained. It is noted that the utility function, being a means to measure the success of a decision that is affected from different factors (*Pavan, Todeschini,2009),* due to the complexity of this application, remains to be an array of the aforementioned different aspects. Finally, the roadmap for the Covid-19 pandemic crisis, considering all the intermediate actions and steps that were necessary in order to confront this situation, can be seen below in Figure 13. In order for this framework to be taken into consideration, one has to take into account that there are two arbitrary assumptions under which it has been formed;

i). The question on the decrease of the demand (annotated in grey colour) should be not done after every step, as it has been considered unlikely to exit an emergency situation in short time

ii). The production shift should be designed early enough (the second grey box)

Figure 13: Roadmap for COVID-19 case

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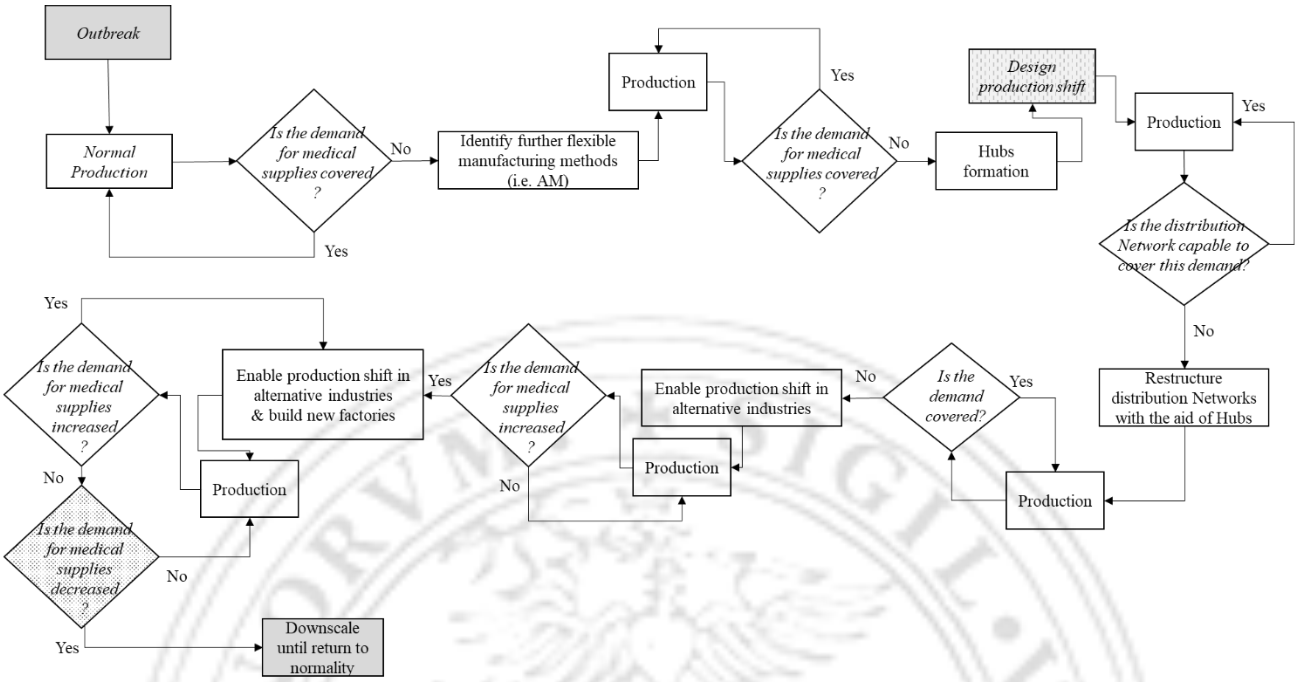

Source: Authors elaboration

7 Conclusion

The ongoing unpredictable socia-financial situation due to COVID-19 pandemic required special treatment in all different fields of everyday life. The industrial world reacted with its own means, taking advantage of the whole inventory of manufacturing processes, in order to cover the demand of medical supplies in a limited time space. The R&D and the commercialization of AM printers, followed by the development of local Hubs, created a network of individuals and traditional manufacturers that were capable to produce low production volume until the non flexible production lines managed to raise the mass production upto the desired levels. The industrial world, organized in consortiums, has provided technologies and infrastructures to face that situtations. The Corporate Social Responsibility (CSR) ideal created the pillars and guide the industrial world to this effort. The expansion of this pandemic was tackled by combining all the available resources and manufacturing processes. To this end, this paper proposed the development of a decision making framework that depends on the parameters that governs every time the situations.

In this work, the process time, the production volume, the flexibility in terms of processing different materials and the ramp up rate, were the main factors that were used as indicators for the process selection. By investigating the capabilities of each manufactuirng process, a hybrid manufacturing solutions was proposed. At the beginning of this effort, Glocal hubs were capable to produce, in very short time, low production volume in order to offer it to local hospitals. During this time, the industrial world was trying to adopt and transform the production lines in order to maximize the production of medical supplies, matching the demand. The combination of the aforementioned solutions with the aid of AM and IM processes, managed to provide enough equipment to cover the global needs for medical supplies in less time than applying each solution individually. However, this call to action was based on the individual companies' internal decision making policies and agenda, thus, a coherent and legislated framework is needed to secure the response in similar future crisis across the world.

As future research, the source of this shortage has to be studied in depth as well as to quantify how the individuals, the small enterprises and the industries managed to reach the desired production levels to counteract this shortage. Moreover, the way that Glocal Hubs were organized can be expanded and analyzed as a means to face similar crisis in the future. The modern means of communication, the automation technologies and the commercialization of AM seem capable to support similar reactions in the future. In Europe and in the Western world in general, the educational programs can adopt lessons that familiarize the young people and the individuals with modern technologies such as Additive Manufacturing, 3D design with Computer Aided Design (CAD) software, e-commerce, etc. that are fundamental for the requirements and the standrads of the modern world and they were crucial to overcome this difficult situation. If people understand and analyze what causes this unprecedented shortage of medical supplies, everyone will be better prepared to face a similar situation in the future, not only for medical supplies but for every kind of equipment. In terms of future technical developments, the manufacturing processes, regadless of the mechanism, ought to be improved in terms of flexibility, ramp-up time and production rate, so that manufacturing succeeds in safekeeping population through meeting demand for emergencies.

Acknowledgements

This work is under the framework of EU Project AVANGARD. This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 869986. The dissemination of results herein reflects only the authors' view and the Commission is not responsible for any use that may be made of the information it contains.

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Regenerative Post COVID-19 Recovery Measures: The Case of Rwanda

Alaa Ben Abdallah[1] and Rudi Michiel Ackerman[2]

[1] International Business and Trade, African Leadership University, Kigali, Rwanda
[2] International Business and Trade, African Leadership University, Kigali, Rwanda

[1]a.benabdall@alustudent.com
[2]rudi.ackerman23@gmail.com

Received: 15/09/2020
Revised: 12/11/2020
Accepted for publication: 07/12/2020
Published: 18/12/2020

Abstract

Governments worldwide are scrambling to combat both the biological and economic effects of the global COVID-19 pandemic. Given urban unemployment and poverty induced by the global pandemic, this paper asks if developing countries could use regenerative agriculture as a form of poverty alleviation. By using Rwanda as a case study, this paper analyzes two of the existent home-grown poverty alleviation initiatives for rural food security: *Girinka* (Have a cow) and *Akarima k'igikoni* (Kitchen Gardens). We investigate if the rural *Akarima k'igikoni* initiative could be implemented in urban areas. Using descriptive statistical data gathered during the pandemic in Rwanda's capital, Kigali, we found rainwater collection practices already well established. We find that many households already separate waste, but that only some households practice composting and home-gardening. We conclude with several recommendations on how the Rwandan government's commitment to sustainable development and urban agglomeration in the Vision 2050 strategy can be achieved. Using already well-established policy mechanisms like the "*Umudugudu*" (=Village) network and the *Akarima k'igikoni* initiative, Rwanda can better weather the economic effects of the global pandemic. These mechanisms present a valuable opportunity for Rwandan businesses to invest in composting activities and regenerative practices in their buildings and waste management systems. Other developing countries can also learn valuable lessons from an environmentally sustainable and home-grown poverty alleviation policy.

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Keywords: Sustainability; COVID19; Rwanda; Vision 2050; Regenerative Agriculture; Circular Food Systems; Decentralisation

1. Introduction

The effects of the global Coronavirus pandemic are yet to be fully quantified, but undeniably had a detrimental effect on the economy and its people (Nicola et al., 2020). As many economies failed the people they are supposed to serve - from health systems and education to sustenance and job security - the pandemic has taught us that there is no option of going back to normal; sustainable practices are not just a nice-to-have but a must-have. The destructive scale of climate change is projected to far exceed the damages caused by the Coronavirus since it endangers our own existence on earth. Climate change-induced temperature increase is "predicted to reach up to 3.25°C by the end of the century" (Bendito and Twomlow, 2015), which is 1.25°C above the degree limit to control climate change repercussions (2°C) (Koch, 2014). Because of their heavy reliance on rain-fed crop production, developing countries and more specifically African countries will disproportionately experience the disastrous effects of climate change such as the frequent droughts and floods and increasing wind speeds that affect, sometimes irreversibly, the crops as well as the initial poverty of the population and limits the capacity to adapt (Mikova et al., 2015). Ironically, while humanity struggled with the economic, social, and biological effects of the virus, the biosphere seemed to recover (NASA, 2020). It is disappointing that it had to take a global pandemic for us to pause our environmentally destructive economic activities. This pause gives us all a valuable moment to reconsider our actions and policies.

In this paper, we will show the key role that sustainability can play in the recovery process after COVID19 for developing countries. By using Rwanda as an example, we will show in the literature review the historical efficacy of regenerative initiatives such as the *Girinka* project. In sections four and five we will use data from a field research study conducted in the midst of the lockdown to show that Kigali may be ready for expanding the *Akarima k'igikoni* project (a more recent regenerative agriculture project launched in 2019) as part of a post-COVID19 recovery process in peri-urban centres. Finally, we present policy recommendations in section six and summarise our findings based on obstacles identified in our field research in section seven.

There are various important solutions that Rwanda has implemented to recover from economic and social hardship after the 1994 genocide against the Tutsi in Rwanda. One such solution was to implement a form of home-grown universal basic income called the *Girinka* project - a system by which all families received a milk cow as a food source. After the food security brought about by the *Girinka* project, and in order to further diversify vitamin intake, the *Akarima k'igikoni* initiative was implemented - a kitchen garden based on circular food system principles. Both these initiatives were supported by the *Umudugudu*[1] network and *umuganda* - an innovative and uniquely Rwandan community service event that proved a very effective way of enacting national policies locally.

Our research builds upon these and other measures. However, our recommendations only represent one piece of the sustainability puzzle - more research into the circular economy, biomimicry, green businesses and renewable energies needs to still be done to help develop a sustainable macroeconomy. We build upon the research done on circular food systems by the Ellen Macarthur Foundation (2019). A more comprehensive review of terms such as regenerative agriculture, circular food systems and composting can be obtained from their comprehensive Cities and Food for Circular Economy report (see Ellen Macarthur Foundation, 2019 and Nijman, 2020).

Our solutions offer guidance around circular food systems that are home-grown, regenerative, and supportive of the urban agglomeration agenda of Rwanda's Vision 2050 development strategy. It is important to realise, as Kolinjivadi put it (Kolinjivadi, in Selby and Kagawa, 2020:3); "[both COVID-19 and climate change] are rooted in the same abusive economic behaviour, and both have proven to be deadly for humans". It is therefore imperative that our economic recovery measures after the pandemic also address (and not further exacerbate) our environmental impact.

2. Context of the COVID-19 pandemic

Rwanda responded to international concerns around the novel SARS strain by installing handwashing stations in and around public transportation hubs, restaurants, commercial centres and banks in its major cities by 11 March 2020. The government tested all incoming air travellers and confirmed the first case on 14 March 2020 - a foreign national travelling to Rwanda. On 16 March, the government declared all large gatherings, education and religious institutions to be closed in the country to limit the spread, and introduced social distancing, mask-wearing and hand-washing rules. These were strictly adhered to with

[1] The closest translation for *Umudugudu* is "village", and is the smallest administrative division in Rwanda. An *umudugudu* normally consists of around 200 - 1000 people, and come together on the last Saturday of every month for *Umuganda*, a collective community service event. Some *Umuganda* days are used for neighbourhood cleanup, repairing of houses or public infrastructure, or the planting of vegetable gardens (*akarima k'igikoni*). For more on the *umudugudu* and *umuganda*, see Uwimbabazi and Lawrence (2013)

penalties like spending a night in the local stadium while being recited the dangers of the virus, among others (Asala, 2020). On 20 March, a full lock-down was implemented with all international flights suspended, non-cargo travel between provinces prohibited, all non-essential travel banned and all incoming travellers were subject to 14-day mandatory quarantine. Only essential services businesses were allowed to operate and movement was strictly enforced with a daily curfew of 9pm-5am. Our own data (Figure 1 below) shows that income levels in our sample dropped by an average of 76 per cent in the sample taken for Kigali during this time of lockdown - mostly because of how hard-hit the informal economy was. Gradually, the Rwandan government relaxed certain restrictions and opened up segments of the economy - most notably the tourism and hospitality industry - which is Rwanda's largest source of foreign reserves (AOEC, 2020). By 1 July 2020, most domestic business activities had been allowed to resume (people were asked to work from home if possible and strict social distancing and mask-wearing policies were in place for those who could not). By 1 August 2020, international flights and tourism had been allowed to resume, subject to strict quarantine and social distancing policies. For the purpose of this study, when we refer to 'lockdown restrictions', we generally refer to the period between March 2020 and July 2020. The data used in this study was collected in the first week of July 2020. As such, it shows the behaviour of households within the peri-urban areas of Kigali after the worst lockdown restrictions have started to lift, as well as their responses during lockdown.

Our study shows that the right conditions are in place in Kigali's peri-urban areas to make use of decentralised regenerative agriculture as a way of poverty alleviation. Most respondents have the right abilities and practices in place to use productive home gardens for sustenance. This is a particularly relevant insight following the depths with which the global pandemic has exposed the thin margin on which much of the informal economy survives. As a developing capital with large peri-urban areas and a large informal economy (Ackerman, 2020), Kigali is a good model for other developing capitals in sub-Saharan Africa. It is also among the fastest growing economies, and the government has a strong focus on industrialising within environmental limits. Our study therefore opens up an avenue for further investigation for developing countries who may also seek to establish regenerative agricultural practices. But it is only the start - more research needs to be done to establish if this is an effective tool for poverty alleviation, and if it can be sustainably scaled in urban centres. Our study merely shows that the potential for implementation exists.

3. Literature Review

3.1. Regenerative Agriculture Overview

The agricultural industry is immensely diverse and has been one of the most defining activities of humankind's development and our impact on the biosphere (Kinahan, 2009). The most common form of commercial agriculture is what can be called 'monoculture', where a single crop is planted at a large scale; fauna and soil minerals are artificially controlled. The monocrop, once harvested, often leaves the fields completely barren, and artificial fertiliser is then needed to plant the next crop. This is contrary to natural regenerative systems where no external inputs are needed to ensure growth (Anderson, 2019). By mimicking natural systems in agriculture, a regenerative circular food system does not need external inputs in the longer run. This may mean planting a diversity of crops that give and take different minerals from the soil, and integrating livestock in agricultural practices more efficiently to mimic natural fauna fertilisation.

Regenerative agriculture has emerged as a compelling field of research and an environmentally fit approach "to adjust our sight to the needs of the new ecology" (Anderson, 2019:2). As such, 'disrupting linear agricultural production' has been a large focus within the research on the circular economy, which evolved into investigating the efficiency of circular food systems. A 2018 study done by Lundgren and LaCanne (2018:1) on corn production found that "regenerative fields had 29 per cent lower grain production but 78 per cent higher profits over traditional corn production systems", which implies that "regenerative farming systems provided greater ecosystem services and profitability for farmers than an input-intensive model of corn production" (LaCanne and Lundgren, 2018:1). The Ellen MacArthur Foundation report on Cities and Circular Economy for Food estimates that for a metropolitan city like São Paulo in Brazil to relocate its farming systems into regenerative practices will yield "USD 67 million cost saving in health due to reduced pesticide exposure and lower air pollution", and "USD 25 million worth of soil saved from degradation in conventional farming practices" (Ellen Macarthur Foundation, 2019:49), and help avoid 92,000 tonnes of greenhouse gas yearly among many other benefits on the individual and communal level (Ellen Macarthur Foundation, 2019). This study hopes to contribute towards the efforts at expanding regenerative agriculture in cities.

What then constitutes a circular food system, and how could we test its viability? Nijman (2020) and the Ellen MacArthur Foundation (2019) suggests implementing a circular system rests on three principles; 1) design out waste, 2) keep products and materials in use and 3) regenerate natural systems. Nijman (2020) applied these principles to regenerative agriculture and considered three variables in a study on East African agricultural practices; 1) the propensity to use organic waste as compost, 2) the propensity to reuse agricultural materials (such as jerry cans and paper bags) and 3) the prevalence of regenerating natural systems (through practices like aquaponics or agroforestry). Because our study is considering households, and not farmers, our study looked at slightly different variables to consider the same three principles. We looked 1) at the the propensity to separate waste (which is an essential step in designing out waste that ends up in a landfill), 2) what most households then do with the waste they separate (is it reused or does it end up in a landfill), and 3) we asked if households capture rainwater (which is a prerequisite for implementing a regenerative urban agricultural system and mimics natural water catchment systems). In addition to these three main areas of investigation, we also considered if alternative water sources are available to test the assumption that rainwater collection is a prerequisite in urban agriculture.

3.2. Recovering from previous challenges; the Girinka Programme

Girinka, which translates to "have a cow," is a Rwandan government initiative launched in 2006 that consists of giving one dairy cow to every low-income family as part of a poverty alleviation strategy. By June 2016, 248,566 cows had been distributed to poor households (Mudingu, 2017). "One Cow brings nutrition, sustenance, and employment, providing a stable income for a family and is a source of soil nutrients via manure to assist small scale cropping activity" (Nyabinwa, 2018:1).

The programme is also in line with the Rwanda Government's priorities for the Transformation of Agriculture (PSTA). On the one hand, as income generated from milk production increases, farmers' abilities to invest in crop production have been on the rise as well as their ability to take loans and participate in development (Unicef, 2012). On the other hand, new cattle breeds have been developed for higher milk yields, and manure was used for crop fertilization and biogas (Unicef, 2012). *Girinka* can be perceived as a form of a universal basic income (UBI). However, since it was non-monetary and culturally appropriate (developed in Rwanda, for Rwanda), it is an interesting and regenerative approach to UBI for a country with limited fiscal ability.

This program was not only created to serve economic purposes but also as a social project to reconstruct Rwanda and reconcile communities after the tragic genocide against the Tutsi in 1994. "If a cow is given from one person to another, it establishes trust and respect between the giver and beneficiary" (Mudingu, 2017:2). *Girinka*'s social dimension has a profound impact on Rwandans' perception of each other because it utilises the cultural significance around the act of giving cows in Rwandan culture - giving cows is traditionally reserved for marriage, where families are ceremonially linked together in the future. In addition, the programme also encourages the use of communal cow sheds as another aspect of fostering connection and knowledge transfer for beneficiaries who are not knowledgeable about cow breeding.

The programme has also contributed to changing the mainstream Rwandan mindset from "looking at cattle as a status symbol (the more cows one had, the better) - to a source of income and livelihood" (Mudingu, 2017:2). By changing this social perception, the negative effects of conspicuous consumption decried by Veblen are avoided (Veblen and Banta, 2007) - most notably that of conspicuous waste. This is an important point, as governments attempt to redefine consumption and consumerism in an effort to achieve decent living standards. Rwanda has shown that by looking inward - at its own cultural roots - the negative consumption patterns that the developed world is now trying to redress, can be avoided. However, as Rwanda gradually urbanises, it is becoming increasingly important to adapt this rural-suited initiative to a more urban setting. With limited land in urban areas, a more appropriate alternative for the future needs to be applied.

3. 3. The Akarima k'igikoni Programme

In an effort to reduce malnutrition, Rwanda's government launched the Akarima k'igikoni initiative as part of a model village planning program in the whole Southern Province in 2019. Child malnutrition is a prominent health issue in Rwanda, with "only 18 per cent of children aged 6-23 months are fed in accordance with the recommendations for infant and young child feeding practices" (Ahishakiye et al., 2019:1). Akarima k'igikoni which translates to "Kitchen Gardens" hopes to provide food diversity especially to young children in order to address poor diets (Kanamugire, 2019).

Not much has been written on this initiative because of its recent implementation. However, it forms part of a series of bigger grassroots strategies for poverty alleviation (such as the *Girinka* programme, among others). For Akarima k'igikoni, the government provides staff, materials, and seeds to build kitchen gardens in each house of the village. There are 338 households sheltering a population of 1525 people who benefited from this program to-date in Gishyushye Village (Kanamugire, 2019). The Akarima k'igikoni program also invests in training people on gardening skills and general knowledge of seeding plants.

Since Akarima k'igikoni uses a participatory approach to build communities, it is seen as building trust between civil society and government - as both work together for the betterment of living conditions and self-sustained living. The government collaborates with the citizens to build the kitchen gardens in all the households of the model village by training them on gardening practices, so they can also help their neighbours in the process. It even involves the community in organising campaigns to collect seeding plants and gardening materials or funds to buy them. "The Executive Secretary of the Rukoma Sector, Nkurunziza Jean de Dieu, urged the people that no one else should make the model a model village except for the people themselves" (Kanamugire, 2019:1). The Akarima k'igikoni is a practical biophilic solution to malnutrition that brings Rwandans together and connects them to their agricultural roots.

4. Research Method

We conducted a series of questionnaire-based interviews in the Bibare, Masoro and Kinyaga cells, which fall under the Gasabo District within Kigali City province. These areas are all located around the newly developed Special Economic Zone / Innovation City, and as such, could be typified as peri-urban.

All data is derived from completing these questionnaires through a verbal interview conducted in Kinyarwanda or English by native speaking fieldworkers, who documented responses (for the full questionnaire, see Appendix 1). A sample size of 151 was used, making the data statistically significant. Where respondents declined to give information, the data point was excluded (see Appendix 1 for the sample size of each question). In general, our sample reflects key similarities with the 2019 census data for Kigali, making the data representative with three major exceptions. Our data has an over-representation of people with secondary school education and above. It also has an over-representation of those working in wholesale and retail trade, repair of motor vehicles and motorcycles. Those working in agriculture are underrepresented - most likely because few farm holdings and many commercial centres were located in the areas where data was collected. In addition, Gasabo has the 2nd highest labour participation rate of all districts in the country, explaining why we have a slight over-representation of labour force respondents in our sample compared to the national average. (NISR, 2020:8). The data collection was funded by the African Leadership University and remains the property of the university.

Table 1. Sample comparison with Kigali population, where available, from NISR data in 2019

Indicator	**Sample Result** *Source: own data*	**Kigali / *National Population** *Source: NISR 2020*
Unemployment*	12.6%	15.2%
Informal Sector* (as percentage of total active labour force)	70.5%	75.8%
Sectors	Agriculture[2] 0.8% Industry 11.4% Services 87.9%	Agriculture 7.3% Industry 19.29% Services 73.4%
Industries	Agriculture (1.1 %) Wholesale and retail trade, repair of motor vehicles and motorcycles (49.5 %) Construction (8.6 %) Manufacturing (3.2 %) Transport and storage (14.0 %)	Agriculture (7.3 %) Wholesale and retail trade, repair of motor vehicles and motorcycles (20.2 %) Construction (10.8 %) Manufacturing (1.0 %) Transport and storage (8.0 %)
Education of Labour Force*	None 22.0% Primary 31.1% Secondary 34.1% Tertiary 12.9%	None 47.2% Primary 29.5% Secondary 16.2% Tertiary 7.2%

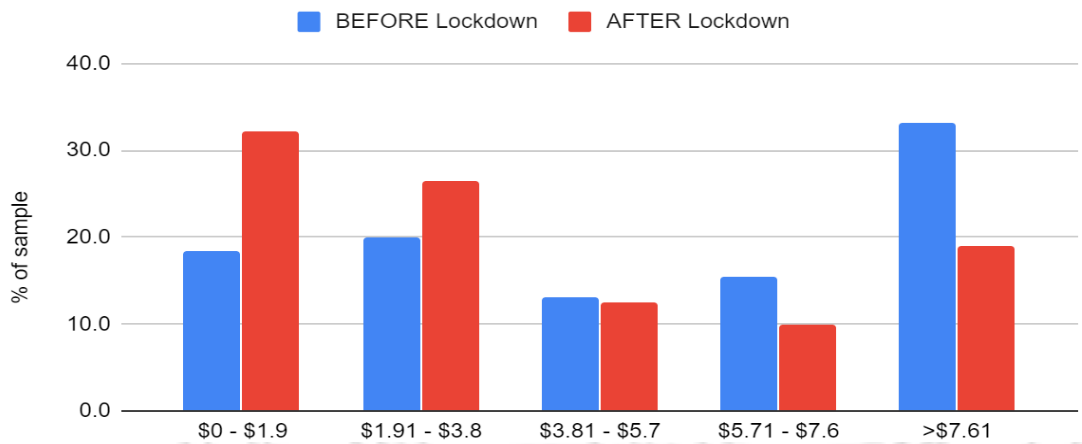
Source: NISR (2019) and Own data (2019)

We analysed the data using descriptive statistics only, mainly because that was sufficient to answer the research questions. More can certainly be done to better understand the full picture of the lockdown on Kigali (*see* Ackerman, 2020)

[2] Note that agriculture here refers to market-oriented agriculture only - subsistence agriculture was excluded from the labour force entirely by both the NISR and this study in line with ILO practice.
*Kigali data not available; figure here is for Rwanda nationally.

Figure 1 shows the average self-reported daily income levels of our sample, adjusted for Purchasing Power Parity to US Dollars. Our data shows that there is a clear negative impact on income levels for our sample because of the Coronavirus pandemic, which supports international literature around the negative effect of the pandemic on the economy. However, respondents self-reported income, and not expenditure, as is best practice for poverty research. As such, the data may not be useful in the literature on absolute poverty prevalence in Rwanda - which was not the purpose of this study. For a more comprehensive review of the poverty prevalence, debates and measurement challenges in Rwanda, see Fatima and Yoshida (2018). For our study, we can only conclude that there is a negative effect on the income levels of our sample. More research should be done, using best-practice consumption-based surveys, to determine the full effect of the lockdowns on income levels during.

Figure 1. Composition of average self-reported daily income levels of sample (adjusted for Purchasing Power Parity)



Source: Own data (n=121)

5. Results & Discussion

5.1 Akarima k'igikoni

Our first area of investigation is to determine the prevalence of these kitchen garden practices among the households in our sample. As an initiative only recently started primarily in the Southern Province, we did not expect to see many households make use of this regenerative agricultural practice in Kigali. Our findings confirmed this expectation - only 5 per cent of respondents reported using their vegetable garden as a way to get food during the lockdown time. Since only 1 per cent of respondents reported working in agriculture, it shows that more people have vegetable gardens at home than work in agriculture - but only by a very small margin. This finding highlights two points; firstly, that vegetable gardens and decentralised food systems are an underutilised form of subsistence in Kigali, even in times of crisis. Secondly, it shows the opportunity for expanding the *Akarima k'igikoni* initiative in urban areas, since very few people currently make use of it.

5.2 Waste categories after separation

Our second area of investigation was around the underlying social practices needed to make a success of decentralised, regenerative food systems. As outlined by the Ellen Macarthur Foundation (2019), having a well-established waste separation culture is a key ingredient for successful implementation of regenerative agriculture. The second step after waste separation is the effective use of composting. Thirdly, access to water is important for vegetable gardening, and finally access to skills and knowledge. In our study, we tested these practices[3].

Considering the first step of waste separation, our data shows that around 21 per cent of the respondents separate their household's waste from their general waste. This can be broken down into the categories shown in Table 2. This means that the practice of separating household waste is already somewhat established (comparatively, only 7 per cent of households in Copenhagen, Denmark demonstrated a high waste separation potential (Pedersen and Manhice, 2019), while 8.13 per cent of South Africans reported separating waste with a slightly higher involvement for urban households at 11.18 per cent (Oyekale, 2017). In addition, respondents were also asked which common packaging items they frequently do not throw away but instead reuse for another purpose. Respondents were given a list of options, and 55.4 per cent of respondents reported reusing packaging frequently for another purpose (Table 4). This also points to a strong culture of reusing items, which is a part of waste separation as well. It shows that Rwandan culture already includes aspects of reusing and recycling, which is only now starting to take root in Europe and the developed world (see Ellen Macarthur Foundation, 2019; Broerse et al., 2014).

Table 2. Percentage of respondents who separate their waste before disposal

Does not separate waste	**78.81%**
Separates waste	**21.19%**

[3] We did not test for skills and knowledge in our study because of the complexity around reliably ascertaining the level of knowledge/skill. As a proxy for this, we consider simply the number of respondents who reported using their vegetable garden as a form of subsistence and support - indicating that enough knowledge and skills exist in order to provide sufficient produce for subsistence.

Categories into which waste is separated[4], as a % of total respondents	Glass	0.66%
	Organic Waste	17.22%
	Paper	1.32%
	Plastic	3.31%

Source: Own data (n=151)

Respondents were also asked *how* they dispose of their waste (Table 3). Only 3.3 per cent of total respondents reported composting their waste[5]. However, the vast majority of people (72 per cent) depend on the government's waste collection, where most of the waste goes through municipal channels and end up in landfills. We can therefore conclude that very few people in our sample made effective use of composting, and there is, therefore, a big opportunity for the *Akarima k'igikoni* to expand this knowledge in urban areas in order to create more circular waste systems. Since around 17.22 per cent of respondents separated organic waste, yet only 3.3 per cent used it for composting, it also represents an important business opportunity for waste management and compost creation businesses in Kigali. The consumer behaviour already seems to separate out waste, but no value is currently being created from this practice.

Table 3. Waste disposal methods used, as percentage of total

Selling waste	1.34%
Burning waste	2.68%
Composting	3.36%
Own landfill	19.46%
Waste Collection	75.17%

Source: Own data (n=149)

[4] Note that the categories do not add up to the total, because some respondents separate into more than one category, and were therefore counted in both categories. As such, this table can be understood to mean that 17.22 per cent of respondents separated organic waste from their general waste, while 1.32 per cent separated paper from their general waste. Some of those who separate organic waste also separate paper, and so on.

[5] This may under represent the total composting practices in our sample. The 3.31 per cent shown here refer to respondents who reported using their organic landfills as compost. However, of those who reported separating organic waste from their general waste 30.77 per cent reported making their own landfill with the organic waste, which is essentially an ineffective form of composting without using the compost itself. Therefore, those who make organic landfills and those who compost make up 8.68 per cent of total respondents.

Table 4. Percentage of respondents who reported reusing the below material for another purpose before disposing of it

Does not reuse packaging frequently		**44.6%**
Reuses packaging frequently		**55.4%**
Products frequently reused, as percentage of those who reported reusing products	Paper Bags	50.36%
	Cardboard Boxes	12.23%
	Plastic Bottles	11.51%
	Plastic Containers	10.79%
	Glass bottles	7.91%
	Plastic Bags	6.47%
	Glass Jars	4.32%
	Paper Cups	3.60%
	Plastic Cups	1.44%
	Metal Tins	0.72%

Source: Own data (n=139)

5.3 Water access and rainwater collection

Finally, we also tested the reliability of access to water. On a macroeconomic level, access to clean water is a prominent issue in Rwanda despite the government's efforts to date. 5.1 million people still lack clean water (WaterAid, 2020), and approximately 60 per cent of rural households drink untreated water (World Bank Group, 2020:92). Although Rwanda has done much to remedy this in the face of the global pandemic by installing simple handwashing stations at most public spaces, these numbers are still concerning.

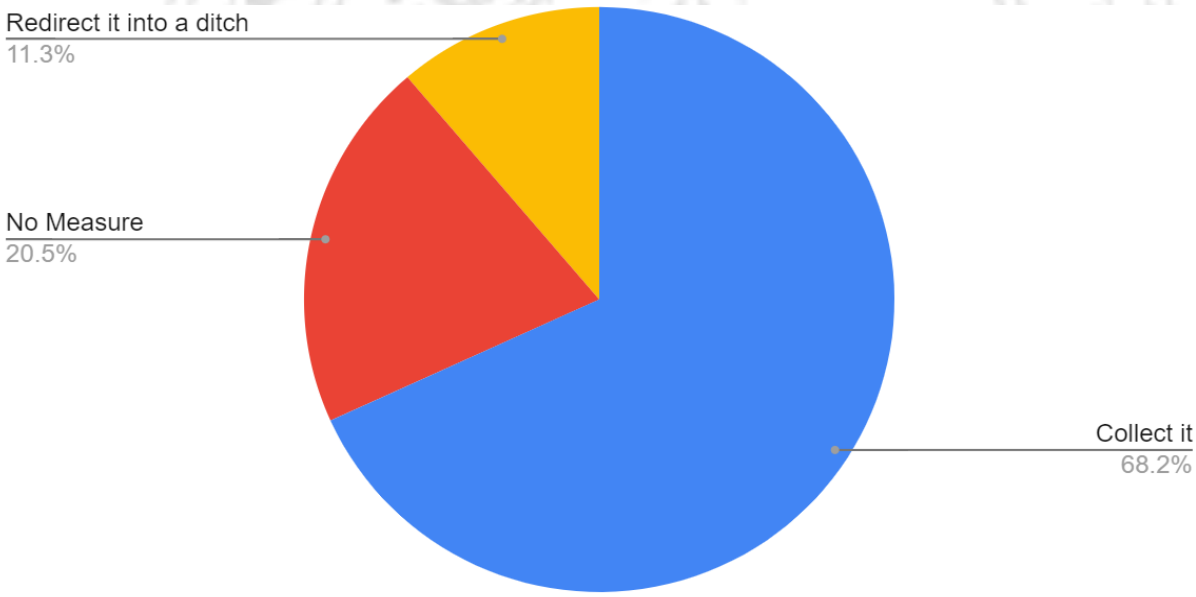
The water problem was clearly observed in the respondents' answers as well; 78.6 per cent reported that they experienced some water cuts for 4 of the days in the week or more[6]. It is possible that this high reported loss of access to water is as a result of the ongoing construction at the nearby Special Economic Zone, but it still points to an underlying problem of consistent water access even in peri-urban areas of

[6] Respondents were simply asked how often they experienced water cuts in an average week. They were not asked about their source of water, but the phrasing implied the source being that of piped water from the Rwandan Water and Sanitation Corporation (WASAC). It is common in the area for people to walk to a WASAC well nearby to collect water in containers that is then used in homes. Our study did not differentiate between respondents who had water piped into their homes, and people who collected water outside of their home from a WASAC tap.

Kigali. It, therefore, suggests that expanding an *Akarima k'igikoni* initiative in the urban centres necessitates fully addressing the water access issues.

Another alternative to the centralised water supply is decentralised water entrapment, primarily using rainwater. Rwanda has a relatively high annual rainfall[7], making this is a viable option for many households. Our data reveals that most households (Figure 2) already entrap rainwater in some way, making rainwater harvesting during COVID19 a vital source of survival. As the government's efforts to expand access to clean drinking water materialise, it is essential that the practices of rainwater harvesting remain - rainwater plays a critical part in the support of a further expansion of Akarima k'igikoni. Hence, it is a good time to introduce the practice of *Akarima k'igikoni* while people still collect rainwater and as government efforts increasingly provide access to grid network drinking water.

Figure 2. Rainwater management at the household level



Source: Own data (n=151)

6. Policy Recommendation: Expanding the *Akarima k'igikoni* Programme

The very successful home-grown *Girinka* project is unsuited for the growing urban agglomeration agenda of Rwanda's Vision 2050. Urban spaces host many malnourished children, with stunting in urban

[7] See https://climateknowledgeportal.worldbank.org/country/rwanda/climate-data-historical

areas in Rwanda documented at 27 per cent (Bosteels and McDonough, 2016). This paper recommends that the government boost the outreach of the home-grown Akarima k'igikoni program after COVID 19 as both a recovery measure and a way to address the malnutrition problem in urban areas. It is also a key ingredient for making the Vision 2050 sustainable and equitable - with further agglomeration and urbanisation of Kigali and other cities, it is important for a circular food system to be well embedded in order to avoid the crippling environmental destruction experienced by the developed world (World Bank Group, 2020). Other developing countries experiencing rapid urbanisation may do well to learn from the Rwandan case - balancing environmental concerns with development is an important global priority.

As our data shows, there is a somewhat well established waste sorting culture, but not yet a well established composting culture in Kigali. Training should be done to teach people composting habits and ways to use organic waste. Similar interventions have been done using Umuganda, and we propose using this as a channel for large-scale education and changing of cultural practices. Phasing out waste from these households and diverting it away from landfills is a valuable step towards circular agriculture. This aligns with the Vision 2050 priority of investing in human capital. According to the strategy, human capital is a very "safe" investment, since "human capital is a portable asset that can have powerful effects on people's welfare and mobility" (World Bank Group, 2020:70).

Apart from changing composting behaviour, it is also essential that the requisite spaces for gardens be incorporated into new developments. Rwandans should be able to also integrate these kitchen gardens in corporate workplaces. The so-called 'living buildings' created by Google and other larger corporations (GER, 2019) are an important trend to follow. Google's efforts to make their campus more waste efficient have "prevent[ed] more than 1 million kilograms (2.25 million pounds) of pre-consumer food waste in its cafés around the world, totalling over 3 million kilograms (6.6 million pounds) of food waste prevented since 2014" (GER, 2019:41). Google keeps producing more innovative solutions towards sustainable business office spaces. Translating the living buildings to a Rwandan context could similarly enable Rwanda to be a front-runner in green urbanisation. The newly built African Leadership University campus in Kigali's Innovation City has adopted measures to encourage reusable water containers instead of single-use bottles, with plans to expand green spaces with food-producing plants for circular campus food production, among others. Similar development should be done in other parts of Kigali, and the government should take a more active lead in ensuring that the new developments in Kigali Innovation

City are representative of global best practice. The *Akarima k'igikoni* should not only be limited to households but can be woven into the fabric of Rwanda's urban scene. Rooftop gardens and green spaces is a great step towards building a Rwanda at the forefront of green innovation. We propose that businesses pilot these green buildings for further analyses of their effect as part of a decentralised food system for urban centres in developing countries. Incorporating these food systems into the industrial symbiosis of the eco-industrial parks proposed by Caycedo (2019) in Rwanda would be a great place to start. In a rising COVID-induced business competition, green practices, sustainable buildings, and regenerative circular urban planning all reflect different models for Corporate Social Responsibility; an excellent competitive advantage to businesses (Urmanaviciene and Arachchi, 2020). CSR does not have to be limited by charity or philanthropy, the need for more innovative and strategic models is evidently urgent and pivotal (Urmanaviciene and Arachchi, 2020) to sustain the economic interests as well as the social and environmental commitment of Rwandan businesses.

In order to support this expansion of the Akarima k'igikoni, the issue of water access needs to be addressed. Several initiatives are currently being implemented to solve the water problem in Rwanda like the WaterAid Rwanda initiatives or the DelAgua Rwanda Project, but their timeline is relatively long. The DelAgua Rwanda Project, for instance, aims to distribute 600,000 advanced water filters to the poorest 30 per cent of households over 20 years (DelAgua, 2020). WaterAid Rwanda has also resorted to training programmes in collaboration with the Centre for Science and Environment (CSE) for state and non-state practitioners (engineers, consultants, planners, academicians, and researchers) on sustainable and affordable rainwater harvesting (RWH) in Rwanda. The purpose of this training overlaps with the vision of managing rainwater in a decentralized way for every household to become self-sustainable with consistent access to water.

This paper supports the governmental push for a holistic decentralized approach to water access in Rwanda through rainwater harvesting and treatment. The government should invest in equipping areas, where there is an existent culture of water collection, with domestic water filters and water collection tanks over the first phase and expand the project with training programs over the second phase. Rainwater harvesting practices have been implemented in some public institutions in Rwanda and have proven to be very efficient in driving sustainability and water-sufficiency[8].

A note on the *Girinka* Programme

As outlined before, the *Girinka* project was a widely successful project for what was a very rural Rwanda post-1994. All our recommendations support the UNICEF recommendation that the project should be upscaled with more donors and partners involved (Unicef, 2012). The *Girinka* program should be reintroduced in Rwanda after the pandemic with a significant focus on government training and skilling activities on cow breeding, composting, and self-managing waste for more sustainable households. Educating the population and developing its human capital is a key driver of economic growth (Zeynalli, 2020); it establishes communication and ensures the alignment between the government's vision and the people's needs. Although our study did not investigate the project or its application in rural Rwanda, it is still part of regenerative agriculture, which is aligned with our recommendations. The production and use of cow manure also have considerable spillovers into the rest of the agricultural value chain. However, considering the grazing and land required to rear cows, it remains a rural solution. Our recommendations aim to address the growing urban areas.

The implementation of proper measurement systems diminishes the high risks of wasted time and resources (Urmanaviciene, 2020). Therefore, we advise that the implementation of these and the previous recommendations be coupled by social impact assessment measures that inform sustainable future governmental planning and policymaking.

7. Summary and Conclusions

In this paper, we discussed the potential expansion of the *Akarima k'igikoni* initiative into urban and peri-urban areas in Rwanda. We investigated the past application of initiatives like the *Girinka* project and the *Akarima k'igikoni* initiative. We considered current cultural practices in the peri-urban area of Kigali's Gasabo District. We found that although most people reuse packaging material frequently, only some portions of the population separate waste. We can conclude that more education should still be done to

[8] For the full report on the potential of rainwater harvesting in the whole of Rwanda, see Matto and Jainer (2019).

support a successful expansion of the *Akarima k'igikoni* programme, starting with education around organic waste disposal and composting. Very few people seem to use vegetable gardens for sustenance, and it, therefore, represents a vastly untapped opportunity for urban food security and circular, regenerative agriculture. We also recommend expanding the *Akarima k'igikoni* in corporate spaces and office parks by adapting the 'living building' concept to a Rwandan context. We found surprisingly prevalent rainwater entrapment practices that could support the expansion of *Akarima k'igikoni* in peri-urban areas. Sustainability can no longer be treated as an externality - it should be a primary driver for policymaking. Our recommendations contribute towards linking the various threads of food security, sustainable decentralised and regenerative agricultural systems, and urban agglomeration.

Limitations of the study

It is important to note that our research was focused in the peri-urban areas of Kigali's Bumbogo, Masoro, Kinyaga and Bibare areas within the Gasabo District. These areas are located in and around the new Special Economic Zone and Kigali Innovation City developments. It, therefore, does not fully represent the more urban, affluent and densely populated areas of Kigali City, nor rural Rwanda at all. Considering the literature on the Akarima k'igikoni, the practice of kitchen gardening seems to be more widespread in the rural Southern Province. This study considers its application in peri-urban Kigali in order to add to the discourse around sustainable agglomeration of urban centres, as outlined in Rwanda's Vision 2050 document.

Finally, this study's data was collected in the first week of July 2020. It is therefore located in the midst of an ongoing pandemic and as such, subject to change during this time. Although questions concerning the topic of this study were phrased to elicit general responses and behaviours notwithstanding the pandemic, it is entirely possible that the time of collection may have skewed the results. We cannot yet know if respondents were more, or less likely, to practice regenerative agriculture during the pandemic time.

Acknowledgements

We express our great appreciation to the African Leadership University in Rwanda for sponsoring this research and for the coordination support from its International Business and Trade, and Operations departments. Special thanks to all the research team members –who are also students at ALU- who helped in collecting data (Blessing Maima Caine, Christian Nsengimana, Euphemia Nusone Perkins, Fiona Uwase, Hassan Damafin Sedekie Jackateh, Oluwasijibomi Adesina, Solomon Mutagoma). We would also like to thank Mr. Aseda Ohene-Adu, a faculty at ALU for his assistance in analysing the data.

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Appendix 1. Questionnaire

NOTE: The full questionnaire included questions relevant to the impact of the ALU campus in that area, as well as questions related to environmental practices. Since those questions were not used in this specific study, they are not listed below. For a full list of all questions asked, contact the authors directly.

Demographic Questions

1. Gender (n=151)
   - ❏ Female
   - ❏ Male
   - ❏ Other…………………..

- ❑ Prefer not to say

2. Age (n=141)
   - ❑ …………
   - ❑ Prefer not to say

3. Nationality (n=151)
   - ❑ Rwandan
   - ❑ Other………………………...

4. If not Rwandan, what are they doing in Rwanda? (n=2)
   - ❑ Working
   - ❑ Visiting
   - ❑ Studying
   - ❑ Other…………...

5. Where do you stay/live (Cell and sector)? (n=149)

………………………

6. Highest level of education attained? (n=147)
   - ❑ Primary
   - ❑ Ordinary level
   - ❑ high school or equivalent
   - ❑ Tvet, Polytechnic institute
   - ❑ Associate degree/ Diploma
   - ❑ Bachelor's degree
   - ❑ Post-graduate degree
   - ❑ Did not attend school

7. What languages do you speak? (n=151)
   - ❑ Kinyarwanda
   - ❑ English
   - ❑ French
   - ❑ Kiswahili
   - ❑ Others………..

8. Employment status (n=151)
   - ❑ Self-employed
   - ❑ Employed
   - ❑ Retired
   - ❑ Unemployed
   - ❑ Other…………..

9. If employed, what is the nature of your employment? (n=42)
   - ❑ Permanent employment contracts (formal)
   - ❑ Fixed-term employment contract (formal)
   - ❑ Casual employment (informal)
   - ❑ Seasonal employment (informal)
   - ❑ Daily employment (informal)

10. What sector have you been working in for the past six months? (n=137)
………………………………………………………………………………...

11. How many people live in your household? (n=150)
………………………………………...

12. How many people depend on you? (n=150)
……………………………

13. What are the sources of your household's income? (n=140)
   ………………………………………....

14. What was the last monthly income **before** Covid-19 lockdowns (Feb 2020) for each source mentioned above? **RWF** (n=142)
   ………………………………………....

15. What is the average monthly income **during** the Covid-19 lockdown (Mar-May 2020) for each source mentioned above? **RWF**? (n=133)
   ………………………………………....

16. What is the average monthly income **now** after Covid-19 lockdown(Jun 2020) for each source mentioned above? **RWF**? (n=124)
   ………………………………………....

17. Did your business shut down due to the COVID pandemic? (n=95)
   - ❑ Yes
   - ❑ No
   - ❑ Partially

18. Did you lose your job due to the COVID pandemic? (n=84)
   - ❑ Yes
   - ❑ No
   - ❑ My pay was cut, but still employed

19. How did you manage to get income for survival during the time of lockdown restrictions? (n=151)

……
………... …………………………………………………

20. How do you dispose of your garbage/trash? (n=149)
    - ❑ Waste Collection
    - ❑ Burn
    - ❑ Own landfill
    - ❑ Composting
    - ❑ Other…….

21. Do you separate your waste before putting it away? (n=151)
    - ❑ No
    - ❑ Organic Waste
    - ❑ Plastic
    - ❑ Paper
    - ❑ Glass
    - ❑ Dangerous Waste
    - ❑ General

22. How much does it cost to dispose of your waste? **RWF**? (n=126)

……

23. Which of these things do you not throw away? (n=139)
    - ❑ Paper Bags
    - ❑ Cardboard Boxes
    - ❑ Paper Cups
    - ❑ Plastic Containers
    - ❑ Plastic Bags
    - ❑ Plastic Bottles
    - ❑ Plastic Cups
    - ❑ Glass Jars
    - ❑ Glass Bottles
    - ❑ Aluminium Cans
    - ❑ Metal Tins
    - ❑ Other……………………..

24. Are you negatively affected by the industrial zone? (n=146)
    - ❑ No
    - ❑ Air/Smoke
    - ❑ Noise
    - ❑ Water
    - ❑ Garbage/Smell

- ❑ Visual
- ❑ Other………………………..

25. How many days in a week do you not have water? (n=146)

……
………

26. How does your Household manage the rainwater? (n=151)
    - ❑ No Measure
    - ❑ Collect it
    - ❑ Redirect it into a ditch
    - ❑ Other………………….

European Journal of Social Impact and Circular Economy

http://www.ojs.unito.it/index.php/ejsice/index

Artificial Intelligence to fight COVID-19 outbreak impact: an overview

Davide Calandra[1] and Matteo Favareto[1]

[1] Department of Management, University of Turin, Turin, Italy

Corresponding author: Matteo Favareto – matteo.favareto@unito.it

Received: 27/08/2020
Revised: 18/11/2020
Accepted for publication: 18/11/2020
Published: 18/12/2020

Abstract

Artificial Intelligence (AI) is showing its strength worldwide in the healthcare sector. Today, in the aftermath of the COVID-19 pandemic, the help of technology appears to be relevant to keep the increase in new infections stable and help medical staff in treatment. Therefore, this paper aims to investigate how AI can be employed against COVID-19 outbreak. Using a multiple case study approach, researchers find out the following insights. First, AI could be used for drugs discovery and knowledge sharing, tracking and prediction, clinical decision making and diagnosis, social distancing and medical chatbots. Second, this paper provides an in-depth analysis of international best practice for tracking contacts and social distance applications. Third, AI technologies could have a transversal impact, also focusing on prevention strategies as a new corporate social responsibility vein. In the end, this paper has theoretical and managerial implications, too. On the theoretical side, we contribute to the extensive discussion about AI and healthcare considering COVID-19 outbreak. On the practical side, we provide medical personnel and policymakers with a tool to understand artificial intelligence and focus investment choices in the practical applications analysed.

Keywords: Artificial intelligence; AI applications; COVID-19; Coronavirus; Health impact; Prevention strategies

1. Introduction

The novel coronavirus disease (COVID-19) has created tremendous chaos around the world, affecting people's lives and causing many deaths. The first cases were detected in Wuhan, China, in December 2019, and now it has been spread to almost every country (Nguyen, 2020). With this growing crisis, companies and researchers over the world are looking for the ways to address the challenges of this virus considering companies and health issue, to mitigate the spread and develop a cure for this disease (Secinaro et al., 2020). In this baffling battle, science, and Artificial Intelligence (AI) technologies are playing a vital role (Kumar et al., 2020).

AI commonly refers to the computational technologies that mimic or simulate processes supported with human intelligence, for instance, reasoning, deep learning, adaptation, interaction, and sensory understanding (Tran et al., 2019). These are technologies that can perform a task that usually requires human perception and judgement (Hamid, 2016). These techniques have an interdisciplinary approach and can be applied to different fields, such as medicine and health. AI has been used in the field of medicine since as early as the 1950s when physicians made the first attempts to improve their diagnoses using computer-aided programs (Frankish & Ramsey, 2014).

The interest and advances in medical AI applications have surged in recent years, thanks to the substantially enhanced computing power of modern computers and the vast amount of digital data now available for collection and utilisation (Tran et al., 2019). AI is gradually changing medical practice. There are several applications of AI in medicine, and they can be used in a variety of medical fields such as: clinical, diagnostical, rehabilitative, surgical and predictive (Jiang et al., 2017; Hamid, 2016). As suggested by Shi et al. (2020), AI could play an essential role in COVID-19 increasing efficiency during working activities and for disease diagnosis, tracking contacts and prognosis. Despite the importance of this field, no studies reviews and discusses the role of AI in tracking services. Therefore, this paper aims to investigate how AI can be employed against COVID-19 outbreak, answering to the following questions: What are companies and labs, around the world, doing to fight COVID-19 outbreak? What could be the central role of AI against COVID-19?

To answer these challenging questions, researchers use a multiple case study theoretical and practical approach to developing the topic. We present the main fields where AI is currently being used and some organisations that are involved in those areas of research.

Finally, the paper is organised as follows. Section 2 will assess an in-depth literature review on the role of AI against COVID-19 outbreak. Section 3 elaborates on the methodology. Section 4 presents the main results obtained. Finally, section 5 will discuss and conclude the paper with future implication for research.

2. Literature review

2.1 COVID-19 and the need for AI technologies to support the research

Naudé (2020); Vaishya et al. (2020); Yassine & Shan (2020) proposed studies in which they analysed how AI technologies can be used in the fight against COVID-19 outbreak. As stated by Yassine & Shan (2020), artificial intelligence is one of the means or avenues to understand the virus and develop preventative and control measures. It includes but is not limited to the usage of mathematical modelling to understand virus transmission, structural biology to determine virus structure and develop vaccines, computational biology to understand virus evolution, as well as docking studies to screen for drugs and inhibitors. AI has the potential to help in all the stages of healthcare, from syndromic surveillance through to rapid diagnosis tests, and faster drug development (Naudé, 2020; Vaishya et al., 2020; Yassine & Shan 2020).

According to Kumar et al. (2020), AI technologies are fundamental tools for tracking and monitoring COVID-19 spread around the world. These technologies are helping in diagnosing the virus and in processing the healthcare claims. Tracking the spread of COVID-19 can be a piece of essential information for public health authorities to design, plan, and deal with the pandemic (Kumar et al., 2020). As stated by Lalmuanawma et al. (2020), contact tracing is a crucial aspect to prevent a wider spread of COVID-19. The process of contact tracing is to identify and manage people who are recently exposed to an infected COVID-19 patient to avoid further spread. In this regard, various infected countries come up with a digital contact tracing process with the mobile application, utilising different technologies. All these digital apps are designed to collect individual personal data, which will be analysed by AI tools to trace a person who is vulnerable to the novel virus due to their recent contacted chain (Lalmuanawma et al., 2020).

Pham et al. (2020); Bragazzi et al. (2020) dealt with how big data and artificial intelligence can help better manage the COVID-19 pandemic. Thanks to the latest advancements in the field of computational techniques and information and communication technologies (ICTs), artificial intelligence and big data can help handle the vast, unprecedented amount of data derived from public health surveillance, real-time epidemic outbreaks monitoring, trend now-casting/forecasting, regular situation briefing and updating from governmental institutions and organisms, and health resources utilisation information (Bragazzi et al., 2020). According to Pham et al. (2020) in the context of COVID-19, big data refers to the patient care data such as physician notes, X-Ray reports, case history, list of doctors and nurses, and information of outbreak areas. Same authors stated that big data potentially provide several promising solutions to help combat COVID-19 epidemic. By combining with AI analytics, big data help to understand the COVID-19 in terms of outbreak tracking, virus structure, disease treatment, and vaccine manufacturing.

Divya et al. (2018); Ahuja et al. (2020) analysed another relevant topic linked with AI and COVID-19: AI-powered chatbots and virtual health assistants. While AI may assist in the discovery of novel drugs and vaccines, it can also help ease the stress placed on medical hotlines. Call centres nationwide that are dealing with the COVID-19 pandemic are notoriously understaffed. Artificial intelligence has the potential to revolutionise public communications and deliver alternative methods to dissipate public information. AI-powered chatbots have been used with success in clinical scenarios and can advise many more people than a staffed call centre. In conclusion, AI-powered chatbots and virtual health assistants are fostering social distancing and streamlining the entire clinical process (Divya et al. 2018; Ahuja et al., 2020).

According to Mahomed (2020); Sun & Zhai (2020); Nguyen et al. (2020), AI can be used to control social distancing. As stated by Sun & Zhai (2020); Mahomed (2020), social distancing avoids direct contacts among people and reduces the potential cross-transmission of virus-carrying droplets from human respiration. By Nguyen et al. (2020) AI technologies play a crucial role in social distancing control. For instance, they allow public place monitoring and can detect, recognise, and identify whether people comply with social distancing requirements or not.

Zhavoronkov et al. (2020); Mohanty et al. (2020) dealt with the topic of AI applications to find out new drugs and treatments. AI can be used to initiate drug discovery and fast-track drug development. These technologies have the potential to improve the drug discovery, planning, treatment, and reported outcomes of the COVID-19 patient, being evidence-based medical tools. According to Mohanty et al. (2020), AI can help, as well, in drug repurposing process. Drug “repurposing” refers to the use of existing approved drugs for the treatment of a never-considered therapeutic indication, in this case, COVID-19. The AI-based drug repurposing is a cheaper, faster, and practical approach and can minimise the failures in clinical trials (Mohanty et al., 2020; Xue et al., 2018).

Table 1 below shows the list of related work includes in the literature review section.

Table 1. List of related work

References	Field
• Naudé (2020); Vaishya et al. (2020); Yassine & Shan (2020)	AI applications in the fight against COVID-19
• Kumar et al. (2020); Lalmuanawma et al. (2020)	AI technologies for monitoring and tracking COVID-19 spread
• Pham et al. (2020); Bragazzi et al. (2020)	AI and Big data for COVID-19 fighting
• Divya et al. (2018); Ahuja et al. (2020)	AI-powered chatbots and virtual health assistants to manage medical call centers and ease public tension
• Mahomed (2020); Sun & Zhai (2020); Nguyen et al. (2020)	AI for social distancing control
• Zhavoronkov et al. (2020); Mohanty et al. (2020)	AI for drugs discovery or repurposing against COVID-19

Source: Authors' elaboration

3. Methodology

To implement the analysis, we employed a case study approach to investigate AI applications against COVID-19 (McCutcheon & Meredith, 1993). For each topic under discussion will be described theoretical items and then practical examples of companies that are currently involved in coronavirus fight.

Because of the virus and the crucial role of AI, nowadays scientific community and companies are focusing more and more on the topic. There are so many firms and labs that are studying the virus evolution to find out a remedy. For this reason, it would have been difficult to describe all of them. For the best of our knowledge, we chose only some companies, and we described strategies and contribution to fight back against COVID-19 spread.

As stated before, we decided to employ a case study approach. According to Yin (2014), case studies can be defined as qualitative research methods that support researchers when "a how or why the question is being asked about a contemporary set of events over which the investigator has little or no control". Besides, qualitative methodologies can usually be better understood by practitioners in leading to managerial practices (Dal Mas et al., 2019), helping to bridge the gap between academia and practice

(Massaro et al., 2018). Additionally, according to Crowe et al. (2011), the collective case study involves studying multiple cases simultaneously or sequentially in an attempt to generate a still broader appreciation of a particular issue.

As suggested by Granello & Wheaton (2004), to collect data, we used different types of online sources:

(1) corporate document and materials;

(2) scientific papers published in peer-review journals;

(3) YouTube interview of the founders;

(4) newspaper articles.

To answer the research questions of this paper, the authors use some study's limitation. Furthermore, all the sources extracted should:

- deal with AI in healthcare;
- link with COVID-19 pandemic topic;
- describe theoretical and practical outputs in terms of COVID-19 response.

Besides, we searched for papers that use a case study methodology to develop the analysis.

Using the criteria mentioned above, we used Scopus and Google Scholar as databases. Thus, the first one is a broad scope database essential for peer-reviewed and conference proceedings analysis (Mongeon & Paul-Hus, 2016). Finally, Google Scholar is an international open-access database that collects information on academic sources in different fields (Falagas et al., 2007).

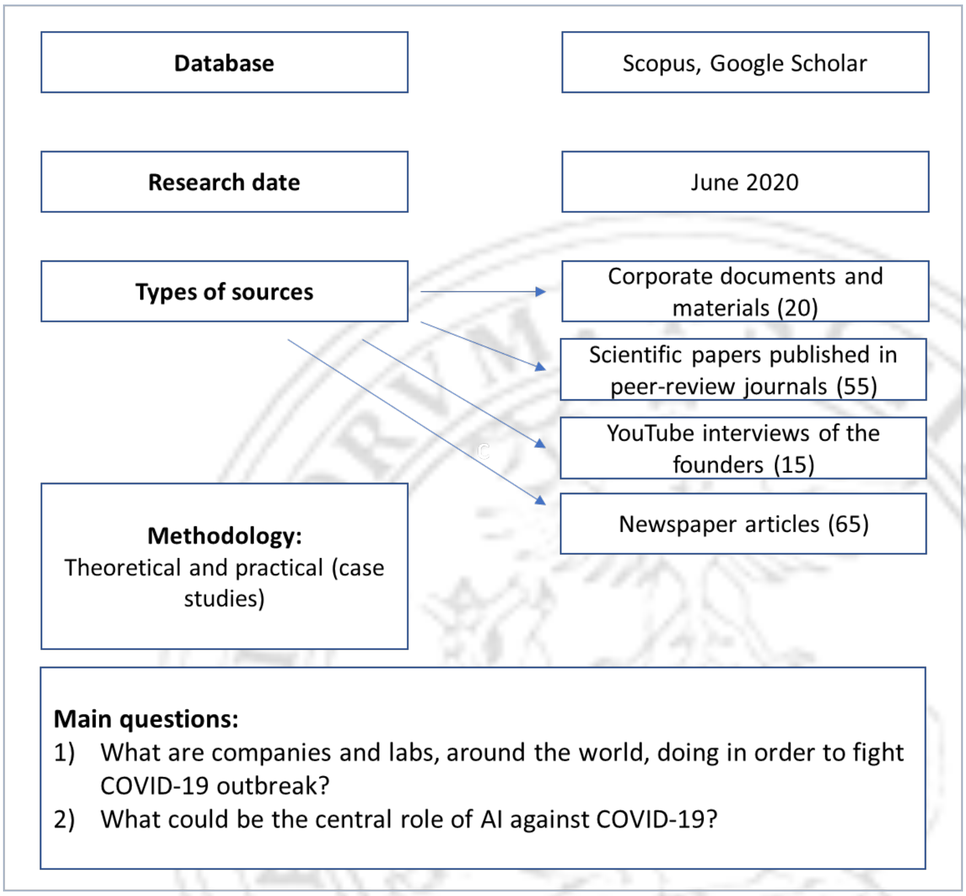
The analysis was implemented using as keywords "*Artificial Intelligence*" and "*COVID-19*" or "*Coronavirus*" and following the objective of the article. Among the search criteria, we focused on English items that were inherent to the searched object.

Overall we got 155 documents divided as follows.

To describe companies' projects, we consulted 20 corporate documents published on companies' official websites. We analysed 55 scientific papers published in peer-review journals, and we watched 15 YouTube interviews of the companies' founders to understand, in a better way, the documents we got and obtaining updates on the topic. Besides, we referred, also, to 65 newspaper articles published by international journals, in different countries, and dealing with the specific topic we analysed.

Figure 1 below shows the methodology used to carry out the analysis.

Figure 1. Characteristics of the analysis



Source: Authors' elaboration

4. Results and Discussion

AI tools and technologies can be employed to support efforts of policy-makers, the medical community, and society at large to manage every stage of the crisis and its aftermath: detection, prevention, response, recovery and to accelerate research (OECD; Naudé, 2020).

There are different areas where AI technologies can contribute to the fight against COVID-19 (Naudé, 2020; Vaishya et al., 2020; Yassine & Shan, 2020): drugs discovery and knowledge sharing (1), tracking and prediction (2), clinical decision-making and diagnosis (3), social distancing control and medical chatbots (4).

Figure 2 shows dominant variables that have been analysed for AI against COVID-19 outbreak.

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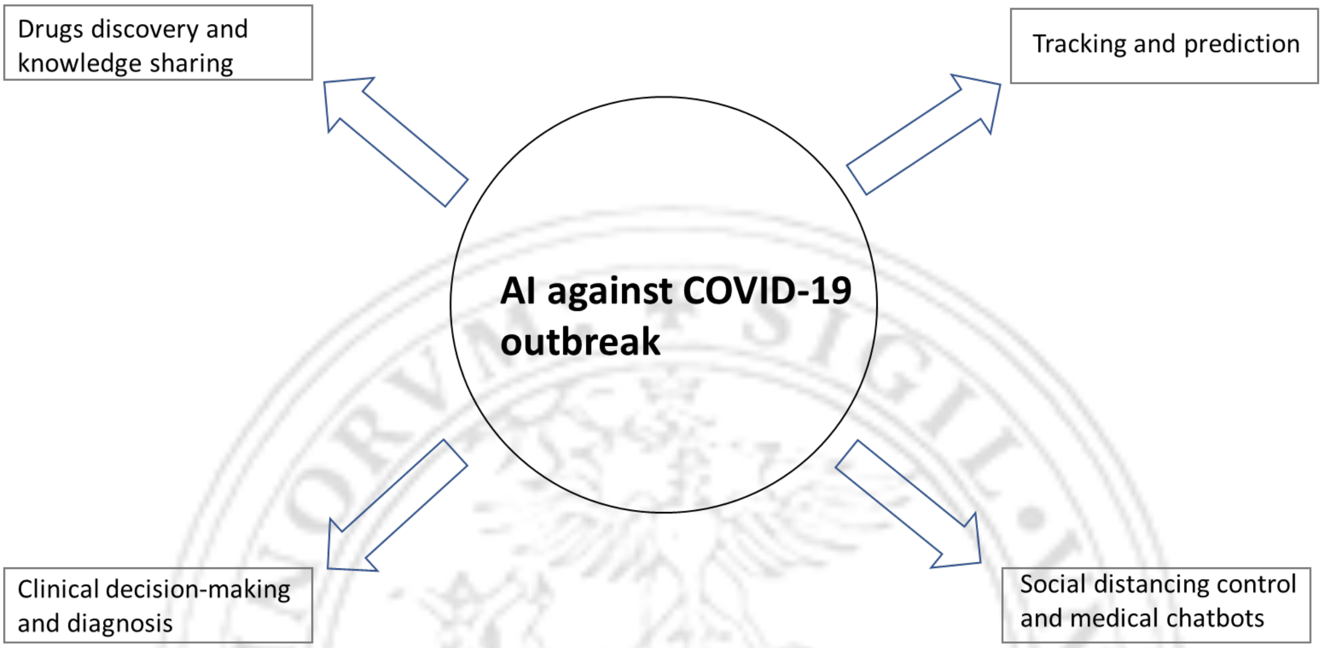
http://www.ojs.unito.it/index.php/ejsice/index

Figure 2. Dominant variables for AI against COVID-19 outbreak



Source: Authors' elaboration

4.1 AI for drugs discovery and knowledge sharing: the DeepMind and Insilico Medicine case studies

The first application of AI to fight the coronavirus is certainly assistance to researchers to develop drugs and treatments to contain the pandemic.

Even long before the COVID-19 outbreak, AI was used for its potential to contribute to new drugs discovery (Naudé, 2020). AI technology is used in speeding up drug testing in real-time, where standard testing takes plenty of time and hence helps to accelerate this process significantly, which may not be possible by a human (Vaishya et al., 2020).

In the case of COVID-19, several research labs and data centres have already indicated that they are recruiting AI to search for treatments for a vaccine against COVID-19 (Naudé, 2020).

According to Ledford (2020) "It is likely to be one of the biggest drug-making challenges the world has ever faced". Several companies are currently involved in this big challenge, and AI technology certainly can help to understand the virus and to accelerate medical research on drugs and treatments.

This case could consider Google's DeepMind with the AI-based model AlphaFold. AlphaFold system can release structure predictions of several under-studied proteins associated with SARS-CoV-2, the virus that causes COVID-19. DeepMind has used AI to predict the structure of the proteins of the virus information that could be useful in developing new drugs (Naudé, 2020).

US company Insilico Medicine represents another example. It is a biotechnology company that was able to use its integrated AI-based drug discovery pipeline to generate new drug compounds against COVID-19. The results revealed a novel method of developing new treatments against COVID-19 while also demonstrating cost-effectiveness and time efficiency (Zhavoronkov, 2020; Mahomed, 2020). Through the use of AI technology, the company was able to categorise thousands of molecules for potential medications in only four days, and these data were then made available for free to researchers (Mahomed, 2020).

Also, AI techniques can support physicians to analyse the thousands of research papers published around the world on the pandemic. Many promising initiatives, however, have been started to gather and share data and to train new AI models. These include the World Health Organization's (WHO) Global Research on Coronavirus Disease Database, which also provides links to other similar initiatives. One of these is the open-access data of the GISAID Initiative. Amongst other initiatives, perhaps the most ambitious is the joint initiative between Semantic Scholar, the Allen Institute for Artificial Intelligence, Microsoft, Facebook, and others, to make openly available the COVID- 19 Open Research Dataset (CORD-19) which contains around 44.000 scholarly articles for data mining (Naudé, 2020).

4.2 AI as an observer and predictor of the evolution of the pandemic: the BlueDot case study

With the help of real-time data analysis, AI can provide updated information which is helpful in the prevention of this disease. It can be used to predict the probable sites of infection, the influx of the virus, need for beds and healthcare professionals during this crisis (Vaishya et al., 2020).

In this sector, the contribution of the Canadian company BlueDot has already become remarkable. It is a global AI database company which uses outbreak risk software, combined their health and medical expertise with advanced data analytics to build solutions that track, contextualise and anticipate infectious disease risks (Mahomed, 2020). BlueDot predicted the outbreak of the infection at the end of 2019, issuing a warning to its clients on 31st of December 2019, before the World Health Organization did so on 9th of January 2020 (Naudé, 2020; Kreuzhuber, 2020).

BlueDot uses an AI-driven algorithm that scours foreign-language news reports, animal and plant disease networks, and official proclamations to give its clients warning to avoid danger zones. BlueDot's reports are then sent to public health officials in a dozen countries, airlines, and frontline hospitals where infected patients might end up.

BlueDot's "Global Early Warning System" combines more than a hundred datasets with proprietary machine learning and Natural Processing Language algorithms in 16 languages, providing an automated surveillance platform that can analyse risks of the virus spread.

Also, according to the information reported on the Council of Europe website, several COVID-19 apps allow tracking and prediction of the virus spread around the world (table 2). For each country is reported: name of the application (1), main functionality (2) and the origin (3). Data are updated on the 10th of June 2020.

Table 2. Overview of COVID-19 apps

Country	Name of the application	Main functionality	Origin
Argentina	Covid-19 Ministerio de Salud	Self-diagnostic	Governmental
Australia	Coronavirus Australia	Quarantine enforcement	Governmental
Australia	CORONAlert	Alerting	Governmental
Australia	COVIDSafe	Contact tracing	Governmental
Austria	StoppCorona	Contact tracing	Governmental
Bahrain	BeAware Bahrain	Quarantine enforcement	Governmental
Brazil	Coronavírus - SUS	Information	Governmental
Brazil	The Spread Project	Contact tracing	Private
Bulgaria	ViruSafe	Contact tracing	Governmental
Canada	Canada Covid-19	Self-diagnostic	Governmental
Canada	Covid Shield	Contact tracing	Private
Canada	Covi	Contact tracing	Private
Chile	CoronApp	Self-diagnostic	Governmental
China	Alipay Health Code	Contact tracing	Private
Colombia	CoronApp - Colombia	Medical reporting	Governmental
Czech Republic	eRouška	Contact tracing	Governmental
Denmark	Smittestopp	Contact tracing	Governmental

Finland	Ketju	Contact tracing	Private
France	StopCovid	Contact tracing	Governmental
France	uTakeCare	Contact tracing	Multistakeholder
France	Alertanoo	Contact tracing	Private
Georgia	Stop Covid	Contact tracing	Governmental
Germany	Coronika	Contact tracing	Private
Germany	Our Health In Our Hands (OHIOH)	Contact tracing	Multistakeholder
Germany	Ito	Contact tracing	Multistakeholder
Ghana	GH COVID-19 Tracker App	NA	Governmental
Greece	DOCANDU Covid Checker	Self-diagnostic	Multistakeholder
Hong Kong	Stay Home Safe	Quarantine enforcement	Governmental
Hungary	VirusRadar	Contact tracing	Governmental
Iceland	Rakning C-19	Contact tracing	Governmental
India	Test Yourself Goa	Self-diagnostic	Governmental
India	Corona Watch	Contact tracing	Governmental
India	Quarantine Watch	Quarantine enforcement	Governmental
India	Mahakavach	Contact tracing	Governmental
India	Test Yourself Puducherry	Self-diagnostic	Governmental
India	COVA Punjab	Contact tracing	Governmental
India	Aarogya Setu	Contact tracing	Governmental
India	COVID-19 Feedback	Medical reporting	Governmental
India	COVID-19 Quarantine Monitor	Contact tracing	Governmental
India	GoK Direct - Kerala	Not Covid-19 specific app	Governmental
India	Trackcovid-19.org	Self-diagnostic	Private
Indonesia	PeduliLindungi	Contact tracing	Governmental
Iran	NA	NA	Governmental
Israel	Hamagen	Contact tracing	Governmental
Italy	allertaLOM	Medical reporting	Governmental
Italy	diAry “Digital Arianna”	Contact tracing	Private
Italy	Immuni	Contact tracing	Private
Italy	Rintraccia dei contatti	Contact Tracing	Private
Italy	SM-COVID-19	Contact Tracing	Private
Italy	CovidApp - Covid Community Alert	Contact Tracing	Private
Jordan	AMAN	Contact Tracing	Governmental
Kuwait	Shlonik	Self-diagnostic	Governmental
Latvia	Apturi Covid	Contact Tracing	Governmental

Malaysia	Gerak Malaysia	Contact Tracing	Governmental
Malaysia	MySejahtera	Information	Governmental
Malaysia	MyTrace	Contact tracing	Governmental
Morocco	Wiqaytna	Contact tracing	Governmental
Mexico	Plan Jalisco Covid-19	Contact tracing	Governmental
Mexico	COVID-19MX	Self-diagnostic	Governmental
Netherlands	PrivateTracer	Contact Tracing	Private
North Macedonia	StopKorona!	Contact tracing	Governmental
Norway	Smittestopp	Contact tracing	Governmental
Poland	Kwarantanna domowa	Quarantine enforcement	Governmental
Poland	ProteGO	Contact tracing	Multistakeholder
Qatar	COVI	Information	Private
Republic of Angola	Covid-19 AO	Quarantine enforcement	Private
Russia	Social Monitoring	Contact tracing	Private
Saudi Arabia	Tawakkalna (Covid-19 KSA)	Quarantine enforcement	Governmental
Singapore	TraceTogether	Contact tracing	Governmental
Singapore	SafeEntry	Contact tracing	Governmental
South Africa	Covi-ID	Contact tracing	Governmental
South Korea	Self-Isolator Safety Protection	Quarantine enforcement	Governmental
South Korea	Mobile self-diagnosis	Self-diagnostic	Governmental
South Korea	Self Quarantine App	Quarantine enforcement	Governmental
Spain	STOP COVID19 CAT	Information	Governmental
Spain	COVID-19.eus	Contact tracing	Governmental
Spain	CoronaMadrid	Medical reporting	Governmental
Sri Lanka	Self Shield	Quarantine enforcement	Governmental
Switzerland	Alertswiss	Not Covid-19 specific app	Governmental
Switzerland	SwissCovid	Contact tracing	Multistakeholder
Thailand	MorChana	Contact tracing	Governmental
Turkey	Korona Önlem	Self-diagnostic	Governmental
Ukraine	Action	Not Covid-19 specific app	Governmental
United Arab Emirates	Tawakkalna (Covid-19 KSA)	Quarantine enforcement	Governmental
United Kingdom	COVID Symptom Study	Medical reporting	Private
United Kingdom	NHS App	Contact tracing	Governmental
United States	Coalition App	Contact tracing	Private
United States	COVID-19 Apple App	Information	Multistakeholder

United States	CovidSafe	Contact tracing	Multistakeholder
United States	How We Feel	Self-diagnostic	Private
United States	Private Kit: Safe Paths	Contact tracing	Private
United States	Covid Watch	Contact tracing	Private
United States	NOVID	Contact tracing	Private
United States	coEpi	Medical reporting	Private
Uruguay	Coronavirus UY	Self-diagnostic	Governmental
Vietnam	COVID-19	Self-diagnostic	Governmental

Source: Authors' elaboration on Council of Europe data

4.3 AI to support physicians in clinical decision-making and diagnosis: the Infervision and Alibaba case studies

Due to a sudden and massive increase in the numbers of patients during COVID-19 pandemic, healthcare professionals have a very high workload. Here, AI is used to reduce the workload of healthcare workers. It helps in early diagnosis and providing treatment at an early stage using digital approaches and decision science (Vaishya et al., 2020).

AI applications can support doctors and medical researchers in the clinical decision-making process. According to Jiang et al. (2017), AI can assist physicians in making better clinical decisions or even replacing human judgement in specific functional areas of healthcare.

For instance, Infervision, a Chinese high-tech enterprise in artificial medical intelligence, created an AI software that flags possible lung problems on Computed Tomography (CT) scans, using hundreds of thousands of lung images collected from major Chinese hospitals. Originally used to diagnose lung cancer, the software is also capable of detecting pneumonia associated with respiratory diseases such as coronavirus. This AI-based technology allows a better understanding of coronavirus cases and makes the process quicker. It represents good support for physicians in their clinical decision-making process.

Another example is the Alibaba DAMO Academy that is dedicated to exploring the unknown through scientific and technological research and innovation. The technology, developed by Alibaba DAMO Academy and Alibaba Cloud, can analyse CT images within 20 seconds for diagnosing suspected novel coronavirus cases with an accuracy rate of 96 per cent. Doctors usually spend around 5 to 10 minutes diagnosing CT images of a patient. The AI diagnosis system can ease the already strained hospital resources (Pham et al., 2020).

Finally, robots can be used to support medical professionals in their daily routine; for example, in China, robots that are typically used in the catering industry are used to clean, sterilise, and deliver food and medicines to reduce human contact. The use of AI technologies should not attempt to replace healthcare professionals entirely but rather assist in improving and fast-track diagnosis while alleviating bottlenecks in the healthcare system (Mahomed, 2020).

4.4 AI to control social distancing and medical chatbots: the Microsoft Healthcare Bot case study

One of the biggest challenges of implementing a defence mechanism against a pandemic is to ensure public participation and acceptance of any mechanism proposed by the authority (Young, 2013). Physical distancing from one another is a critical part of ensuring that the virus does not spread.

AI has been argued to be necessary to manage the pandemic by using thermal imaging to scan public spaces for people potentially infected, and by enforcing social distancing and lockdown measures (Rivas, 2020). For example, China's sophisticated surveillance technology uses facial recognition and body temperature to identify whether an individual has a fever and therefore, could be a carrier of the virus (Mahomed, 2020).

An AI-based computer vision camera system has been used in the UK to monitor adherence by individuals to social distancing measures. More controversially, Israel's cyber monitoring system enables its security services to identify and quarantine people who may be infected (Naudé, 2020).

Also, several companies are investing in the development of medical chatbots based on AI. These technologies can screen people and advise whether they should be evaluated for the infection. They enable "at-home risk assessments" in a few minutes. AI-powered virtual health assistants and chatbots, enable self-service, drive better outcomes, and reduce costs (Divya et al., 2018). Moreover, they can ease the stress placed on medical hotlines (Ahuja et al., 2020). Chatbots are fostering social distancing and streamlining the entire clinical process.

The Microsoft Healthcare Bot is an example of this technology. The service combines built-in medical intelligence with natural language capabilities, extensibility tools and compliance constructs. That service allows healthcare organisations such as Providers, Payers, Pharma, Health Maintenance Organisations (HMOs), Telehealth to give people access to trusted and relevant healthcare services and information.

Virtual health assistants and chatbot technology will never replace medical personnel. Nevertheless, technology can help make better use of medical personnel's time and relieve some of the burdens from the healthcare system (Bitran, 2019).

4.5 AI-based technologies: a transversal impact

As we described, AI technologies have a crucial role in the fight against COVID-19 and can be used in different ways and applied for a wide range of purposes. AI is not only helpful in the treatment of COVID-19 infected patients but also for their proper health monitoring (Mahomed, 2020). It is also useful to facilitate the research on this virus using the available data. AI can help in developing proper treatment regimens, prevention strategies, drug and vaccine development (Vaishya et al., 2020).

In this sense, AI-based technologies are essentials because they can generate a positive transversal impact on society and healthcare organisations (Naudé, 2020). These technologies, also, can contribute to the optimisation of logistics processes in hospitals and allow a better allocation of resources for firms (Jiang et al., 2017).

In the end, considering prevention strategies, AI-based technologies can support companies' enhancing their social responsibility (Pan, 2020). In this sense, as discussed by Zhao (2018), COVID-19 could allow businesses to consider alternative corporate social responsibility challenges.

5. Conclusion

Digital technology, including information technology and AI, are therefore proving to be essential tools to help build a coordinated response to this pandemic. In our research, we focused on central areas of applications where AI technologies are currently impacting against COVID-19, and we analysed some practical cases. Table 3 shows the elements under discussion and case studies that have been analysed in our paper.

From our analysis came up with some crucial insights.

First, we described how AI technologies play a crucial role in terms of contact tracing and monitoring of the pandemic spread. For this reason, governments around the world are investing more and more to develop COVID-19 apps. These AI-based technologies can allow storage of data that could be useful for tracking "*hot zone*" and create global alert of high-risk pandemic areas.

Secondly, we observed that high-tech companies around the world are embracing a more healthcare-oriented approach. Big players are even more oriented to create a positive impact on society and are developing new technologies that can help to fight the virus.

This paper showed that the use of modern technology with AI improved the screening, prediction, contact tracing, forecasting, and drug/vaccine development with extreme reliability (Lalmuanawma et al., 2020). Considering these platforms assists AI experts to analyse massive datasets and help physicians train machines, set algorithms, or optimise the interpreted data for dealing with the virus with more speed and accuracy (Jamshidi et al., 2020). The analysis highlights, as well, that AI techniques are a fundamental tool for clinical decision-making. They can be used in different ways and applied for a wide range of purposes. Applications based on AI simplify work for physicians and medical staff providing them meaningful insights.

This paper has theoretical and managerial implications; in fact, it could be useful either for researchers or professionals (*i.e., policymakers, physicians, managers, healthcare, and administrative staff*). We wanted to underline that artificial intelligence applications are fundamental to contain the spread of the virus and to find out a vaccine as soon as possible. Analysing some AI applications, we aimed, also, to help healthcare organisations to allocate their financial resources better and investing more in these technologies. Finally, we chose to describe AI applications against COVID-19 to allow a better understanding of these techniques and help other professionals to gather what currently exists.

Like any research, this paper has some limitations.

First, the writing period did not allow the researchers to deepen their knowledge in the practical field. This element represents a future strength that will lead to a more in-depth analysis considering new methodologies. For example, future investigations could include the targeted analysis of individual case studies.

Moreover, at the level of business models, it would be interesting to analyse how the perception of Tech companies has changed compared to the previous and current period of COVID-19.

Table 3. Elements under discussion and case studies analysed for each topic

Macro variables	Case studies
• Drugs discovery and knowledge sharing	DeepMind; Insilico Medicine
• Tracking and prediction	BlueDot
• Clinical decision-making and diagnosis	Infervision; Alibaba
• Social distancing control and medical chatbots	Microsoft Healthcare Bot

Source: Authors' elaboration

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