MANUFACTURING CHANGE

A Framework for Scaling Distributed Manufacturing in the Global South

FRONTIER TECH HUB

UKaid from the British people

ACKNOWLEDGEMENTS

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ABBREVIATIONS

AI	Artificial Intelligence
AT	Assistive Technology
CNC	Computer Numerical Control
DM	Distributed Manufacturing
FCDO	Foreign, Commonwealth & Development Office (UK Government Department)
FT Hub	Frontier Technologies Hub
LPLS	Local Production, Local Solutions
NGO	Non-governmental Organization
PPE	Personal Protective Equipment
WASH	Water, Sanitation and Hygiene

CONTENTS

INTRODUCTION

In this report, when talking about Distributed Manufacturing (DM), we refer to an approach to production that involves making goods in smaller quantities, in more locations, close to the point of use.

The rise of DM has been fueled by advances in technologies such as additive manufacturing, computer-aided design, and cloud computing, which enable local manufacturing to be more accessible and flexible. Such approaches have been growing since the 1990s, a growth first driven by large-scale industry and the military sector. Over the past ten years, there has been an increase in interest in how it may be applied in development and humanitarian contexts to address both supply chain challenges and livelihoods. A boom in the visibility of distributed manufacturing resulted from the disruptions in global supply networks that the COVID-19 pandemic caused in 2020-21, and although the publicity and organized networks have now faded from view, the same manufacturing capacity is still there – but it has gone back to making the variety of things it was making before the pandemic hit.

DM has the potential to reduce costs, lead times, and environmental impact while enabling the production of customized or small-batch products tailored to local needs and preferences. It is particularly important in the provision of products that need to be personalized, such as assistive technology.

DM can represent a shift from centralized production to more context-appropriate manufacturing in the Global South. The key dilemma of scaling DM is the question over whether it remains a way to fill a few gaps in otherwise global supply chains, or whether it has the potential to scale and transform major systems.

The Frontier Technologies Hub (FT Hub) has supported three DM pilots over the past eight years, with a fourth currently in the scoping phase[1]. The evidence from those pilots plus a range of additional case studies (included as Appendices) was reviewed for this report. Based on the findings from those cases, plus a review of the available literature, this report explores the challenges and opportunities associated with scaling distributed manufacturing in the Global South[2]. It offers a framework of strategies and provides recommendations for donors, investors, policymakers, and entrepreneurs in support of scaling distributed manufacturing. By doing so, this report aims to contribute to the development of a more sustainable, equitable, and resilient global manufacturing ecosystem.

[1] These pilots are: 3D Printing Nepal (2017-18); Kijenzi – Manufacturing for the next frontier, Kenya (2021-22); Data Aggregation and Distributed Manufacturing - BRAC, Bangladesh (2021-22); and Distributed Manufacturing Frontier Technologies Scoping for South Pacific (2022-23).

[2] It is important to note here that in post-colonial research, we recognize that dividing the world into North and South, center and periphery, and people into experts and non-experts is a tool to maintain the status quo. Especially as DM invites those "non-experts" to contribute to innovation, the researchers of DM also need to understand that there is not one unified Global South: findings cannot be generalized. We also need to keep in mind that the same issues addressed by DM can arise in the North as they can in the South.

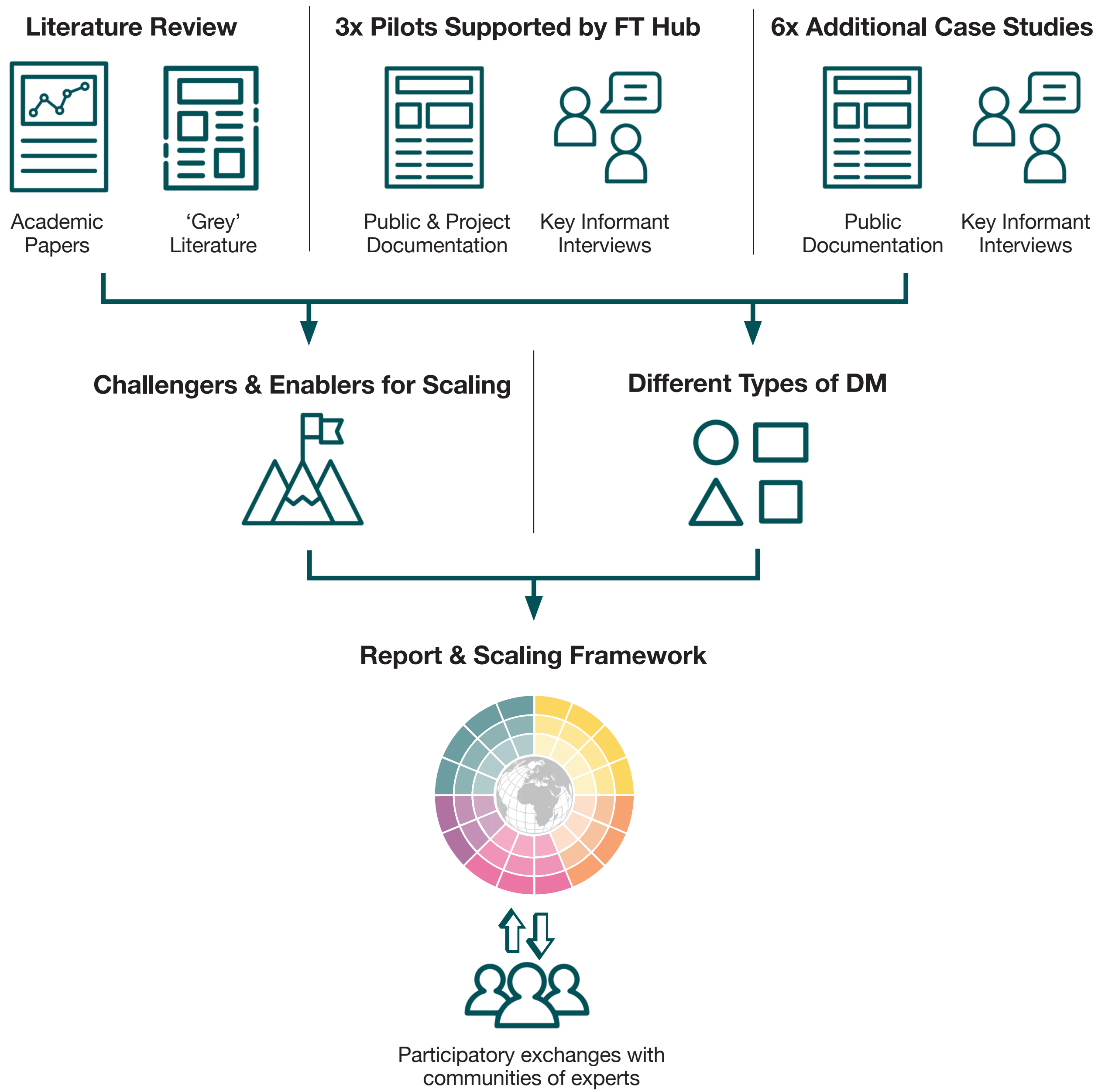
METHODOLOGY

This study aims to gather and share learnings on the potential for scaling Distributed Manufacturing in the Global South. It has been undertaken with the Frontier Technologies Hub, which works with UK Foreign, Commonwealth and Development Office (FCDO) staff and global partners to understand the potential for innovative tech in the development context, and then test and scale their ideas.

LIMITATIONS

The resources and literature on the scaling of distributed manufacturing, especially in the Global South are very limited. Furthermore, there is no consensus regarding the definitions of scaling and distributed manufacturing. Finally, large industrial entities and the military are reluctant to disclose detailed accounts of their practices. Although the report builds on literature from other sectors (such as humanitarian and social innovation), and the cases cover a broad range of practices to learn from, findings cannot be generalized for the whole geographic area called “the Global South”, which is a vast and diverse set of contexts.

It is also important to note that all DM initiatives reviewed have been successful enough for us to hear about them. This raises the possibility of survivorship bias: we may have missed challenges so big that they have stopped other initiatives from ever getting off the ground.



THE BASICS

WHAT IS DISTRIBUTED MANUFACTURING?

There is no generally accepted definition of Distributed Manufacturing (DM). We understand it as a decentralized approach to production that enables **smaller-scale manufacturing** much **closer to the end-user**, often leveraging recent **breakthroughs** in production and infrastructure technologies. In this model, products are designed, produced, and distributed through a **network** of local or regional manufacturers, rather than being manufactured at a centralized location and shipped to customers.

In some contexts DM is considered to be defined by the use of flexible manufacturing technologies (digitally controlled machines that can produce different items one after another just by loading a different design file). For our purposes, we have chosen to use a looser definition that can also include manufacturing with more traditional technologies but making use of modern technologies for communication or coordination – because this can deliver many of the same benefits.

When using a broad definition of DM, it can be helpful to distinguish between different types, so in the 'Findings' section below we have identified three dimensions on which examples of DM can differ: product variety, network type, and degree of coordination.

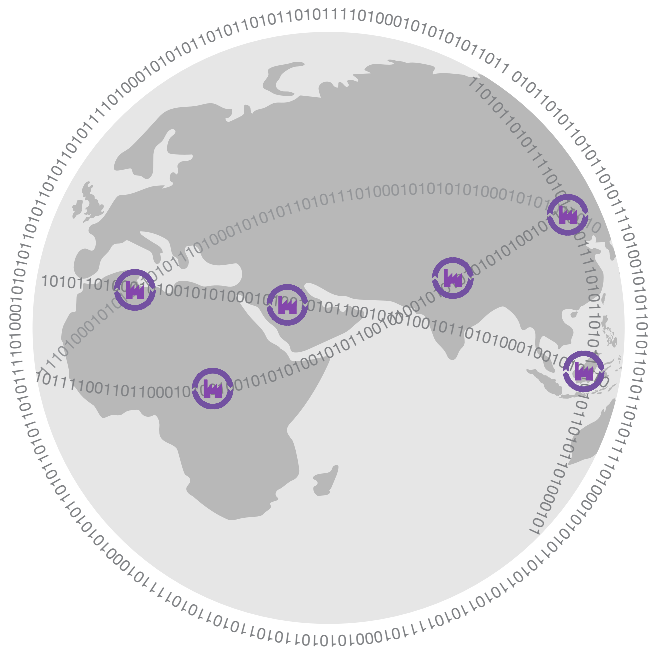
Finally, what does 'closer' to the end-user mean? Again, there is no simple definition that makes sense in all situations. It doesn't even need to be within the same country, as there are many places where products sourced from across a border are more local than those brought from the capital of the same country. And, creating a production facility for a region (e.g. in Kenya to supply all of the East African Community) delivers far more of the benefits discussed below than importing from the other side of the world.

20th Century
Mass Manufacturing

Long global supply chains are
slow and inefficient

Flow of goods and materials

21st Century
Distributed Manufacturing



Keeping goods and materials local saves
time and resources

Flow of data

A NOTE ON TERMINOLOGY

When it comes to manufacturing being done close to the user, there are a variety of terms used for similar or overlapping emerging concepts. To make matters more confusing, several of them can be used to mean different things, and most of them are used inconsistently. The most frequently used terms are Distributed Manufacturing (DM), Re-Distributed Manufacturing (an approach that prioritizes sustainability and circularity more than DM), Local or Localized Manufacturing (a community-focused approach that emphasizes social responsibility more than DM), and Decentralized Manufacturing (a flexible and distributed approach in which – contrary to DM's network approach – multiple production sites remain under one company's ownership).

Although these terms are not completely synonymous, the differences between them are subtle and they are used inconsistently enough that it does not create a helpful framework for understanding what is being done. For the purposes of this report, the term "Distributed Manufacturing" is used throughout.

WHAT DO WE MEAN BY SCALING DM?

Most academic and grey literature emphasizes that business and scaling models are developed through iterative processes that involve trial and error as responses to changing social, political, economic and technological landscapes, and do not follow a linear pathway. Even traditional businesses can struggle to efficiently and effectively manage their growth in the early stages, lacking the necessary strategies, processes, talent, systems, and metrics. This holds true also for DM, which is a relatively new type of venture.

One of the difficulties in scaling DM is that it does not scale in a linear fashion. There are network effects that affect costs and revenues differently at different scales, and moving from a single node to multiple creates more need for oversight or centralization of some functions.

Scaling in general refers to expanding a business or operation in a way that allows it to handle increased demand or output. In the context of humanitarian and economic development, scaling often involves

> "building on demonstrated successes to ensure that solutions reach their maximum potential, have the greatest possible impact, and lead to widespread change.
>
> Elrha. (2018) 'Too Tough to Scale? Challenges to Scaling Innovation in the Humanitarian Sector.' Elrha: London

In order for DM as a solution to reach its maximum potential, have the greatest possible impact, and lead to widespread change, it will be necessary to think about scaling at the sector and ecosystem level, not just the scaling of individual DM initiatives.

WHAT ARE LARGE MANUFACTURERS DOING WITH DM?

Many large-scale manufacturers use Distributed Manufacturing as an approach (moving production closer to where items will be needed) It can be argued that manufacturing at various production sites owned by multinational corporate actors is a form of DM, whether or not they use this term themselves. In many cases, they are also meeting the tighter definition of DM as using flexible manufacturing technologies such as 3D printing, laser cutting, and Computer Numerical Control (CNC) machining. Spare part production is by far the largest area where actors in the private and defense sectors use DCM – instead of stocking them or waiting for them to be shipped, spare parts are being produced on site, in the Global North and South alike.

Other examples of DM utilized by global corporations include:

- Until 2017, sports apparel company Adidas tested a program called "Knit for You" that allows customers to design and order custom knitwear online. The production of the garments was done at a facility in Germany using 3D knitting machines.
- Boeing has in 2015 partnered with – and in 2018, invested in – the additive manufacturing firm Morf3D to produce 3D printed aluminum and titanium components for its satellites and helicopters. The parts are manufactured at Morf3D's facility in California and then sent to Boeing for final assembly. Boeing has also established a network of additive manufacturing facilities across the United States.
- General Electric (GE) has established a global network of 'brilliant factories' that use digital manufacturing technologies such as robotics, 3D printing, and sensors to produce a range of goods, including jet engines and gas turbines.
- Computer and printer manufacturer HP has launched a program called 'Print-to-Order' that allows customers to design and order custom 3D printed parts online. The parts are produced at a facility in China and then shipped to customers worldwide.
- Engineering firm Siemens has established a network of 'digital factories' that use advanced manufacturing technologies such as robotics, artificial intelligence, and additive manufacturing to produce a range of goods, including medical equipment and wind turbines.

Examples of DM utilized in the defense sector include:

- Defense contractor Lockheed Martin is using 3D printing to produce parts for a range of products, including fighter jets and missiles in a network of additive manufacturing facilities across the United States. BAE Systems is using 3D printing to produce components for a range of products, including fighter jets and tanks, in a network of additive manufacturing facilities across the United States and the United Kingdom.
- Raytheon has developed a mobile 3D printing system that can be used in remote locations to produce replacement parts and tools.
- The United States Army is utilizing 3D printing to produce replacement parts and tools in the field. The Army has also developed a mobile additive manufacturing lab that can be transported to remote locations.

The keys to successful additive manufacturing are quality control and logistics. Corporations generally follow two main approaches: Building DM systems within their own companies, or collaborating with service providers. Service providers in Europe who are certified to produce parts for industries such as health, aerospace and space include Materialise with its consultancy branch Mindware, as well as EOS who have recently launched a Contract Manufacturing Network in collaboration with Makerverse. Through this network, clients can upload technical drawings and immediately get quotes from several producers – such a network could lead to manufacturing much closer to the end-user, especially when it comes to spare parts production. Wikifactory offers a similar network[5] which aims to also include open-source approaches, while e.g. Siemens' Additive Manufacturing Network[6] offers a closed network only to customers and certified suppliers of Siemens.

One recent example for a local DM network in the so-called Global North is the 'Production Next Door' project. It aims to research a new way of cost-efficient and locally producing customized products, particularly furniture, in the Hamburg metropolitan region. The product development involves global developer communities, while local craftsmen and small or medium-sized production companies produce the final products.

[5] https://wikifactory.com/platform/manufacture/
[6] https://additive-manufacturing-network.sws.siemens.com/

WHY MIGHT DM BE USEFUL IN A DEVELOPMENT CONTEXT?

Distributed Manufacturing (DM) offers the potential for various advantages over traditional centralized manufacturing practices that are built on long, unresponsive supply chains, are far from the consumer, and use scarce resources inefficiently.

USER PROXIMITY

DM enables the production of customized or small-batch products tailored to local needs and preferences. This leads to less logistics costs and more distributed natural capital/material sources. With DM, local production can be more accessible and flexible, reducing the distance between the producer and the end-user.

ON-DEMAND PRODUCTION

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

DM enables on-demand production, which means that products can be produced when they are needed, reducing the need for high inventory and thus circumventing issues of high inventory value. This lowers the cost of production and minimizes waste, making it a more cost-effective, sustainable, and socially conscious manufacturing model.

RESILIENCE

DM offers resilience to the vulnerability of global supply chain disruptions. In times of crises, such as the COVID-19 pandemic, traditional centralized manufacturing practices were unable to adapt quickly to changing demands and supply chain disruptions. In contrast, DM's capacity to rapidly prototype, test, document, produce, and reproduce necessary products makes it more resilient to crises and disasters.

SUSTAINABILITY

13 CLIMATE ACTION

DM can support sustainability efforts, particularly in models of re-distributed manufacturing (RDM) through repair and the circular economy. DM operations can benefit from more distributed natural capital/material sources, reducing the impact on the environment.

INDIVIDUALIZATION

DM offers models based on personalization or individual needs, which can go beyond context-specific changes to a design. This can be especially interesting in fields where large companies have no incentive to act, such as assistive technologies, where individualization is especially crucial. DM can scale to geographic areas where it is most needed, such as in post-conflict areas, through technologies that enable personalization, such as 3D scanning and additive manufacturing.

PARTICIPATION

8 DECENT WORK AND ECONOMIC GROWTH

DM is not merely Industry 4.0 and Smart Manufacturing, i.e., digitalization and smart machines. It also encompasses participation, extending to the end-user from design to production, meaning that new societal considerations are made possible. DM supports a shift from centralized production to more context-appropriate manufacturing in the Global South.

CHANGING CONSUMERISM

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

DM has the potential to change the social context of consumerism, make circular economy approaches cheaper and more effective, and offers new opportunities for the production of customized or small-batch products tailored to local needs and preferences.

It should be noted that some of the important advantages of DM create the biggest challenges in implementation - for example the combination of node replication (producing the same thing in different places) and flexibility in what products are made create a uniquely difficult situation for managing quality.

FINDINGS

The case studies and literature investigated for this study produced findings that can be organized around four categories:

1. **DIFFERENT TYPES OF DM** – this sets out the ways in which the case studies differed, and was used to interpret the insights that emerged from them.
2. **FRAMEWORK** – This introduces a tool that groups topics important to the success of DM under five different headings and considers the levels at which they can be addressed (micro, meso, and macro).
3. **SUCCESS FACTORS** – originally looking for 'Challenges & Enablers', we noticed that in different contexts the same topic could be either hindrance or a help.
4. **STRATEGIES** – This takes the framework and gives the strategies identified for addressing each success factor at each level.

Map of Case Studies

CASE STUDIES

The nine case studies on which this report draws, given in Appendix 1, are:

3 x Pilots supported by FT Hub:

BRAC – The world's largest NGO is buying locally manufactured products to support the Rohingya refugee response, and working through some of the barriers to a huge organization engaging with many small suppliers.

Kijenzi – A 3D printing company that puts localized, distributed manufacturing to work for institutions who do the public good. With FT Hub support, Kijenzi has experimented with different business models including hub-and-spoke approaches to scale while maintaining high quality.

Nepal 3D Printing – A pilot with an NGO (Field Ready) has led to the development of a thriving distributed manufacturing ecosystem in Nepal, with multiple independent actors, now also expanding into other digital manufacturing technologies.

6 x Additional Case Studies:

Beneficial Bio: a network of independent labs produces enzymes locally with support from the network. Quality control aided by open-source software, and a future ISO 13485 certification enable them to scale over multiple locations. Labs in the UK and Cameroon, and projects in Ghana, Ethiopia, Kenya, Chile, and Argentina, are helping to create more equitable access to biotech and skills distribution.

Maker's Asylum: From being as a small makerspace focusing on educational projects, Maker's Asylum mobilized resources during the Covid-19 pandemic, catalyzing a network across India that produced more than 1 million face shields and enabled the local manufacturing and repair of oxygen concentrators.

MoTIV: Through its network of hubs in Kampala, Mbarara, Jinja and Gulu, as well as its Virtual Factory Network, MoTIV is helping to create a more diverse and resilient manufacturing sector in Uganda, responding quickly to market changes and driving positive social and economic change in the region.

Protege BR: To help gain agility, achieve quality and organize the production capacity of makerspaces and small-scale manufacturers during the COVID-19 pandemic, Protege BR was a collaborative network connecting makers, manufacturers and healthcare professionals, testing sites and supporting distribution.

Robries: Giving single-use plastic a new, multi-use life by recycling it into modern furniture. Combining the power of waste banks and the open source Precious Plastic Machine, the young team have created a manufacturing business that needs to scale fast, as it can barely keep up with demand.

Wazi Vision: Using local designers, digital manufacturing technologies, and innovative social business models, Wazi Vision is on a mission to improve eyecare health for all Africans. Their model enables localisation of frames and customisation of glasses at varied price points to increase access.

1. DIFFERENT TYPES OF DM

All case studies reviewed for this report could be described as Distributed Manufacturing, but they have very different characteristics. Three dimensions have been identified on which the models differ:

- **PRODUCT VARIETY** – or how flexibly a workshop can produce different items;
- **NETWORK TYPE** – or a typology of nodes and networks built around them;
- **DEGREE OF COORDINATION** – or how closely coordinated the different nodes are.

PRODUCT VARIETY

Every item different ⟷ Every item the same

The classic technology-based view of Distributed Manufacturing is of a workshop with a flexible machine producing completely different items to meet hyperlocal needs - for example, using a 3D printer to make a toy one minute, a cooking utensil the next, and perhaps a spare part for a machine after that. In practice all the examples reviewed for this study had some degree of market specialization and/or were seeking products they could make in batches significantly larger than one[7].

Although none of the case studies are at either extreme of the spectrum[8], it is certainly true that they vary along it. Zener Technologies in Nepal generates a significant amount of revenue from making architectural models, which are all different. The PPE examples made large numbers of products with little variety (face shields and masks). Also towards the more standardized end of the spectrum is Beneficial Bio, which has a catalog of standard products (although the product mix offered in different locations can vary according to local demand). Somewhere in the middle of the spectrum is Wazi Vision, because although the individual products produced are almost all different from each other due to the large numbers of possible combinations, there is a strong market specialization (glasses) and a moderate range of components (a defined range of frames, and finite range of possible lenses).

NETWORK TYPE

A typology of four different kinds of network is shown in the box on the next page. Starting with a single node, it may be seen to offer options on how to scale. However they are not absolute alternatives: it is possible for a single initiative to operate in more than one type of network. Network type may also change over time. Kijenzi has at different times operated as a single node, a hub-and-spoke network, and during the pandemic they produced PPE in a product network (different components made by different manufacturers, assembled and quality tested by a central entity).

DEGREE OF COORDINATION

Informal collaboration ⟷ Common ownership

The third way in which the case studies differ is by how closely coordinated the different nodes are, ranging from informal collaborations (most likely to be knowledge networks) through those in which demand or processes are coordinated, through to networks where all nodes are under common ownership and thus have a single locus of control. Examples of the latter situation are typically seen with a large commercial organization that owns multiple hubs where spare parts for their equipment can be made, in the military, and in the hub-and-spoke model that Kijenzi has experimented with. The Covid-19 PPE manufacturing networks typically had no formal agreements in place between nodes but in addition to knowledge sharing there was often some attempt to coordinate demand in order to route it to available capacity, as seen e.g. in the case of Protege BR in Brazil, or the M19 Initiative in India. The BRAC model was unique among our case studies in that it was the customer playing the role of demand coordination. Further along the collaboration-control spectrum are networks that standardize operations or production processes and are typically under one brand. Beneficial Bio is an example of this, where the independently owned & operated nodes commit to maintaining the same production standards.

The looser the network, the more flexible it is, and the advantage is that new nodes can be added more easily and with less investment.

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[7] This is likely to be for two main reasons: firstly because although the machine changeover times for flexible manufacturing equipment are minimal, the design time (and attendant prototyping runs) are significant. Being able to spread the design time over the production of more units will thus make each unit far cheaper, since the machine time and material cost are in many cases insignificant compared to the hours a skilled professional must spend on design. Market specialization leads to a more efficient sales process, even if the actual items produced are different - such as in the architectural models (it is also likely that there is the possibility to re-use some of the design work at the component level even if the finished product is not the same).

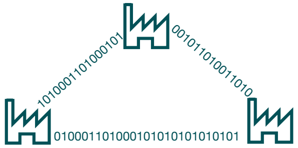
[8] As a thought experiment, the authors considered whether an operation making a completely standardized product (every item the same, for example brick manufacture) would be considered 'Distributed Manufacturing'. The conclusion was that it could - in the sense that it is possible to imagine more and less distributed approaches to making bricks. They could be made in a centralized way and shipped to where they are needed, or made in a highly distributed way with brick making equipment on every construction site, or anything in between. Furthermore, the majority of the success factors outlined (BELOW) would still apply to the more distributed cases.

Single Node

It is arguable that one single production facility, not connected to any kind of network is not really an example of distributed manufacturing. However, an organization always intending to create a network will usually start as a single node, and the decisions they take are geared towards the creation of a network. Hub and spoke operations may also retrench to become single nodes in times of difficulty.

Single Node Case Studies

- Kijenzi
- Robries
- Wazi Vision

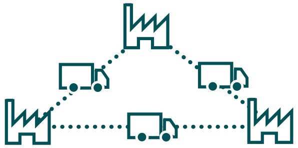


Knowledge Network

In a knowledge network, information (in the form of ideas, designs, know-how, processes & procedures, blueprints for machinery) is shared between nodes but products do not move. This is probably the ‘purest’ form of Distributed Manufacturing, and what many people have in mind when they conceptualize the topic. Open source blueprints are shared among members of the Precious Plastic community, enabling Robries to tackle the plastic problem in Indonesia; or open science hardware communities that share projects in the GOSH network worldwide are examples that have even further reaching impacts, influencing policies for example.

Knowledge Network Case Studies

- Nepal 3DP
- Beneficial Bio
- Maker’s Asylum
- Protege BR
- Robries

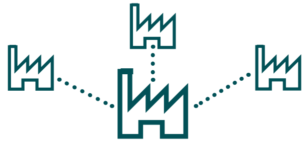


Product Network

In a product network, it is physical products, components, or materials that move between nodes. When used for standardized products, this is not conceptually different to a normal supply chain. An example of a product network that is more clearly an example of distributed manufacturing is where there are many different manufacturing facilities with different capabilities, and a huge variety of customized products can be made with different routings though the network. This setup is found quite often in the informal sector, for example Suame Magazine in Kumasi, Ghana and Dharavi in Mumbai, India. In both cases, within a relatively small area, there are thousands of small workshops each with their own specialist skill and equipment. A product may visit many workshops at different stages in its journey, having different operations performed on it.

Product Network Case Studies

- Kijenzi
- Protege BR



Hub & Spoke

This approach combines nodes with different levels or types of capability into a network. It can also be thought of as a special case of either a knowledge network or a product network: an example of the former was used by Kijenzi (prototyping was done at a remote node and all production orders were fulfilled from one hub), and an example of the latter was used in the LPLS initiative where one node (Clintonel) was able to make a mould that was then used in production by another node. Zener Technologies in Nepal acts as a kind of advanced technology hub supporting many more traditional manufacturers and artisans. It is also possible to imagine that this model could be used so that certain critical components are manufactured at hub level (those that require higher skill, tighter quality control, or more expensive equipment) and those are then shipped to spoke nodes where less critical steps are performed closer to the customer.

Hub & Spoke Case Studies

- Kijenzi
- BRAC
- MoTIV
- Nepal 3DP

2. FRAMEWORK

DM is an approach rather than a particular model, and the “Global South” is a disparate collection of vastly different contexts both within and between countries. This Framework was designed to be used as a tool to think about how different challenges related to the scaling of DM can be addressed. It outlines 5 key scaling strategies and how those can be approached on 3 distinct geographical and political levels.

MAKE
Relating to making products

OPERATE
Relating to operating the organization that does the making & selling

COLLABORATE
Relating to working with other stakeholders in the DM ecosystem

SELL
Relating to selling products in the market

INVEST
Relating to the need to invest in order to grow or scale DM

3. SUCCESS FACTORS

Sixteen factors were identified as important for Distributed Manufacturing. They can act as challenges or as enablers depending on the context, such as the state of the factor and the type of DM in question. The factors are explained in the tables on the following pages. They can be grouped under the following overarching topics:

MAKE

- Access to Inputs
- Access to Skills
- Quality & Compliance
- Technology Readiness

SELL

- Market Knowledge
- Market Readiness
- Procurement Policies
- Transaction Friction

OPERATE

- Infrastructure
- Regulatory Environment

COLLABORATE

- Access to Knowledge
- Collaboration Culture
- Community

INVEST

- Experimentation
- Business Model
- Access to Funring

4. STRATEGIES

All the success factors outlined in the previous section can be addressed at three different levels, defined by how widely the solution will be applicable.

Micro – Solution applies to the individual company or initiative only
The default is usually that DM orgs will first try to solve problems at this level. With more knowledge sharing & evidence reviews, micro level solutions can also help the broader sector.

Meso – Solution will apply within a geographic ecosystem – which may range in size from a neighbourhood to a multi-country trading bloc.
This is the level of regulatory systems and government policy; although it can also be influenced by collective action from other actors or in some cases by single actors within the ecosystem providing services for all

Macro – Solution will apply globally.
Globally applicable solutions are typically either tools or knowledge that can be shared openly, to support implementations that must be rooted in local context

The tables on the following pages give examples of strategies to address the success factors at each of these levels of applicability.

Often it is not the case that the challenges are individually insurmountable; rather the issue is the cumulative effect on the organisation of managing or solving them. The expenditure of resources to manage challenges – whether money or time – gives DM organisations higher cost structures and lower reliability and agility than would otherwise be the case. This impacts on the success of individual DM orgs and on the sector as a whole.

MAKE

FACTORS			STRATEGIES		
	Example as Challenge	**Example as Enabler**	**Micro**	**Meso**	**Macro**
Access to Inputs	Key materials having to be specially imported with long lead times and high transport costs	A plentiful local resource (such as bamboo or plastic waste) can be used as an input	• Direct import • Invest in processing facilities to have needed input available	• Local / regional distributors • Pooled procurement arrangements	• Shared information on material equivalences & alternatives
Access to Skills	Having to train people for 6 months before they can start doing useful work	Finding the right person with the right mix of skills can be catalytic	• Invest in training workers	• Partnership with a local TVET institution or makerspace • Identify existing communities with transferable skills	• Develop & share open curricula • Develop best practice policy suggestions for governments to review
Quality & Compliance	Unreliable quality or inability to provide adequate documentation putting customers off	ISO certification giving customers confidence	• Experiment with different materials & processes • Process documentation • Invest in better tools or more highly skilled people	• Address input availability quality issues • Offer training on quality management across an ecosystem • Appropriate national regulation of standards	• Open source ERP / process documentation tools • Better information on how to manage quality • Development of open standards that DM orgs can adhere to
Technology Readiness	Using a machine that is not ready for industrial use, leading to frequent downtime and customer dissatisfaction	Reliable & affordable technology at an appropriate scale	• Improve the design of machines so they work better / work in the local context	• Shared access to more advanced equipment	• Greater investment in affordable, reliable technologies with good documentation

SELL

FACTORS			STRATEGIES		
	Example as Challenge	**Example as Enabler**	**Micro**	**Meso**	**Macro**
Market Knowledge	Lack of data on local populations and businesses hampers the ability to assess the feasibility of different products	Deep understanding of the needs of customers can lead to generation of innovative solutions	• Individual market research • Trial and error	• Publish market data & surveys	• Develop guidelines for key data to be published
Market Readiness	Poor market perception of locally produced goods can make it difficult to sell	High demand coupled with global supply chain failures during the Covid-19 pandemic created a lot of demand for PPE and other products that could not be satisfied by imports, making buyers willing to purchase locally made	• Invest in marketing • Invest in customer education or address local need	• Marketing campaigns for locally produced goods • Having open access makerspaces where people can see new technologies	• Shared case studies & marketing materials that can be used to demonstrate potential
Procurement Policies	Large buyers unable to contract with small manufacturers	Large buyers having procurement approaches to enable them to work with small manufacturers and that value the social surplus generated by DM when considering bids	• Get informed about and comply with policies	• Harmonise requirements across multiple buyers to reduce compliance burden	• Develop & share best practices for enabling procurement of locally made goods
Transaction Friction	Cumbersome contracting or payment processes	Mobile money to make small sales quick and easy	• Make it as easy as possible for customers to contract & pay you	• Increase access to mobile money • Make template contracts available for particular legal systems	• Make distributed contracting systems available • Make template contracts available

OPERATE

FACTORS			STRATEGIES		
	Example as Challenge	**Example as Enabler**	**Micro**	**Meso**	**Macro**
Infrastructure	Unreliable internet access or electricity	Reliable fast internet access can ensure a company has access to the global knowledge base and can communicate with customers	• Invest in backups to infrastructure e.g. solar panels / generator; wireless broadband	• Direct investment in infrastructure • Pooled investment in infrastructure backups	• Collect evidence on the economic impact of different types of infrastructure
Regulatory Environment	Some national regulators lacking the capacity to test locally made products	Expedited processes created during the pandemic in several countries made it more feasible than usual to get locally made items approved	• Build relationship with regulatory bodies • Drive the creation of advocacy groups by finding others affected by the same issues	• Invest in product testing capability • Advocating: to support the governmental development of regulations and (start-up) acts	• Discover & share regulatory best practices

COLLABORATE

FACTORS			STRATEGIES		
	Example as Challenge	**Example as Enabler**	**Micro**	**Meso**	**Macro**
Access to Knowledge	Little accessible information on how to manage quality in DM	Availability of reliable open source designs with full documentation	• Research and experiment • Manufacturers to collaborate with makerspaces and similar innovative communities to exchange knowledge	• Mapping existing regional manufacturing capacities • Collect and share information about locally available materials that can replace materials that need to be sourced from elsewhere	• Invest in knowledge generation & sharing mechanisms
Collaboration Culture	Working in silos, everyone duplicating effort to solve the same problems	Different organisations willing to pool expertise to work together on common objectives	• Identify & cultivate partners, build networks for scaling	• Invest in local and regional networks	• Invest in global networks that enable collaboration and exchange (including South-South and North-South-South)
Community	Entrepreneurs feeling isolated with no-one to bounce ideas off	Entrepreneurs feeling supported & inspired	• Find support	• Create peer support mechanisms & local/ regional networks	• Create global peer support mechanisms & networks

INVEST

FACTORS			STRATEGIES		
	Example as Challenge	**Example as Enabler**	**Micro**	**Meso**	**Macro**
Experimentation	Lack of ability to experiment hampers success	An entrepreneur having a job in the right field while experimenting to understand what would work as a business	• Seek employment that will allow experimentation • Keep overhead costs low & sunk cost investments to a minimum before hypotheses are fully tested	• Create structures that support organizations to experiment	• Share actionable insights based on others' experimentation to reduce duplication of effort
Business Model	Uncertainty over a financially sustainable business model	Getting the business model right can unlock funding as well as generating revenue	• Iterative approach: trial & error	• Share market intelligence data	• Share information on tested business models and the contexts in which they have worked or failed
Access to Funding	Lack of capital to invest and working capital to fund the order cycle make it impossible to grow	Appropriately designed funding pots for all stages of the scaling journey	• Underinvest • Seek funding from many different avenues	• Work on the market for DM to make businesses more investable	• Develop funding mechanisms that bridge the gap between innovation funding and scaling funding

CONCLUSION

A review of the evidence for scaling DM in the Global South suggests that it is still early to point to certain approaches being more successful than others. The relatively small number of initiatives that have successfully scaled, coupled with the vast differences in context make it impossible to say yet with any certainty that certain models of scaling will be more successful. Many DM organizations and initiatives are experiencing growth challenges, while those that are expanding are still exploring different models. There is not one linear pathway for any DM project, but iteration and rapid responses to changing social, political, economic and technological landscapes are necessary.

One overarching finding from all case studies and discussions is that DM organizations and initiatives are internalizing costs to do things that could be more efficiently provided at the ecosystem level or even globally. Firms are training their own workers rather than being able to hire people with the right skills; are creating designs for spare parts rather than being able to download a file from an open database; are individually battling against INGO procurement policies rather than engaging with a sector that knows how to work with actors that benefit the local economy. This means that the costs are higher and sales lower for DM organisations than they would otherwise be; this makes it more difficult to scale, which in turn inhibits the growth of the ecosystem that would lower costs and encourage sales.

One exception was the collective efforts of industry, makers, governments, regulators, and end-users during the Covid-19 crisis. Crises are regarded as catalysts for DM by interviewees and workshop participants, and in light of the multitude of crises in the anthropocene, a rise in DM is to be expected. The predicament of scaling DM thus becomes obvious: Collective efforts within ecosystems and networks are required for sustainable scaling, yet the lack of examples and success stories makes it hard for these ecosystems and networks to develop.

Beyond a single organization or company, efforts to scale DM must take into consideration the development of **ecosystems**, i.e. systems of actors and stakeholders that can work together to achieve shared goals, promoting local economic development, and building local manufacturing capacity, in an environment that fosters collaboration, innovation, and the sharing of resources and knowledge. This approach involves building partnerships across different sectors and industries, creating networks of support and resources, and developing shared standards and protocols.

Finally, DM itself constitutes a frontier technology, as it is emerging or developing rapidly, has the potential to significantly impact societies and economies, and is characterized by high levels of uncertainty and risk. At the same time, DM offers opportunities to adopt other frontier technologies, ranging from e.g. metal 3D printing as a frontier additive manufacturing technology, via machine learning (ML) and artificial intelligence (AI) for designing products and #offlinefirst enterprise resources planning (ERP) software as frontier software technologies, to pushing systemic frontiers, e.g. by including DM platforms in attempts to establish Smart Cities, as suggested by the Fab Cities approach.

When it comes to DM, scaling across an ecosystem involves expanding production capacity and increasing the reach of manufacturing operations while maintaining the decentralized and community-based approach that characterizes DM. From this perspective, a checklist for scaling DM includes

- ☐ building partnerships, including strong relationships with local communities
- ☐ standardizing manufacturing processes
- ☐ automating manufacturing and administrative processes
- ☐ building the capacity of all actors and stakeholders
- ☐ investing in skills development, knowledge transfer, and infrastructure
- ☐ creating a supportive policy and regulatory environment
- ☐ prioritizing social and environmental sustainability in all aspects of operations
- ☐ marketing the benefits of DM

It is vital to keep in mind the intended benefits when trying to scale something up, and DM is no exception. The reasons for wanting to scale DM include social, economic, and environmental arguments; scaling DM thus requires taking a holistic approach that considers the impacts of manufacturing operations on all these dimensions.

RECOMMENDATIONS

WHAT CAN DEVELOPMENT AGENCIES DO?

Prioritize socially oriented approaches to procurement: INGOs, as large buyers of many goods necessary in humanitarian & development contexts, and donors (who influence policy), need to take their role as market shapers seriously. Approaches such as taking 'Social Surplus' into account when spending public or aid money, and shifting requirements from products to the provision of the benefit that the product delivers when it works, need to be explored and tested.

Explore innovative financing models: Access to finance is critical for scaling DM initiatives. There is an urgent need for intermediate scale funding to bridge the gap between innovation funding (typically in the tens of thousands or low hundreds of thousands of pounds) and scaling funding in the tens of millions. Development agencies could explore innovative financing models, such as crowdfunding, impact investing, and investment pools, to support DM networks in the Global South.

Reverse the internalization of various costs: Steps are needed to reverse the internalization of costs by DM organizations, including supporting the creation of other ecosystem actors (such as distributors of imported materials, makerspaces as prototyping & learning centres) and supporting the creation of tools and mechanisms that make it easier to share what knowledge already exists.

Support the development of an open database of spare parts designs: this is long overdue, also in light of the producer lifecycle responsibility. Several companies already offer closed databases, advocacy by organizations such as the Internet of Production Alliance should be supported by development agencies. Access to designs for local manufacturing of spare parts should at a minimum become a requirement for aid-funded equipment.

HOW CAN GOVERNMENTS HELP?

Share procurement best practices: The role of the state in driving and shaping the market - as a big potential customer, and as a rule setter - should be given particular attention. Changes are needed to how tenders are managed, for example to include flexible manufacturers who can make many different things. Sharing procurement best practices would be one important step towards enabling DM networks to become vendors of governments.

Develop regulatory frameworks and industrial policies that support DM: Clear regulatory frameworks that support DM networks, including policies that encourage the use of open source software and hardware, establish standards for DM, and promote collaboration between DM organizations, makerspaces, and traditional manufacturers should be developed. Governments could also offer tax incentives and subsidies to encourage investment in DM.
Invest in local testing and certification capacity: Too many countries have limited capacity to approve locally made products or approaches to product certification that are extremely difficult and costly for small manufacturers to navigate. The growth of all kinds of local manufacturing would be supported by addressing these issues.

Map local manufacturers: To build on existing manufacturing capacity to scale DM, local manufacturers who are disconnected from each other should be mapped. The information generated should be openly accessible, and continuously iterated and while it might become a governmental resource supporting the work of a chamber of commerce or trade ministry, it should be part of the commons and remain in the ownership of the community.

WHAT TYPES OF MULTI-STAKEHOLDER COLLABORATION ARE NEEDED?

It is necessary to **implement a multistakeholder approach** to scaling DM in the Global South, with practical solutions and actions taken by different stakeholders, including DM organizations, policymakers, traditional industry leaders, regulators, INGOS, and innovators.

Establish a Knowledge Sharing Group for more international collaboration: DM is such a fast growing approach and knowledge is produced similarly rapidly, a multidisciplinary group of practitioners, researchers, decision makers, and enablers needs to be established and facilitated, with the aim of frequently gathering to share experiences, grow as a network, and create opportunities for emerging knowledge to be exchanged and harvested.

Collaborations between industry, DM organizations and makers and innovators: While we see some evidence for such collaborations in Nepal 3D Printing and Makers' Asylum, as well as in MoTIV and Protege BR setting up platforms for collaboration, these examples remain scarce, despite them offering big opportunities for engaging more stakeholders in DM ecosystems.

Advocating for investors to focus on DM: Investors who are committed to integrating ESG (Environment, Sustainability, Governance) factors into investment decisions and asset management will be more likely to invest in DM initiatives. We recommend DM networks and support structures to advocate for more investment in DM especially with bodies such as the UN Global Compact and the signatories of the Principles for Responsible Investment (PRI).

Connecting DM with open hardware, open source software, and frontier technologies: DM does not exist in isolation. Connecting DM with Open Hardware and Open Source Software (e.g. open source AI, ML) as well as Open Science is the most promising approach for scaling DM in the Global South. For example, several interviewees highlighted the need for open-source offline first enterprise resource planning (ERP) softwares to be developed, which would support smooth operations, quality assurance, and easier cash flows within DM networks. Developments in other technologies such as AL Quality Control approaches also offer great promise.

HOW TO SUPPORT CAPACITY BUILDING FOR THE SCALING OF DM?

Collaborative capacity building programs: To equip more people with the necessary skills, knowledge, and resources to successfully implement and scale DM initiatives, novel programs should be established. There is a need for technical education (in 3D design skills and use of different digital manufacturing technologies) for people engaged in traditional manufacturing, including in the informal sector; and a need for more entrepreneurial and business training for people who already have the required technical skills. These programs could be supported by development agencies, industry leaders, and other stakeholders.

Develop a Self-Assessment Tool: The framework presented in this report could be developed into a Self-Assessment Tool of factors for DM practitioners to use regularly, so they can identify areas they need to work on, develop strategies to do that, and measure their progress in overcoming challenges.

FURTHER RESEARCH

In the Global North and South alike, there are still more questions than answers when it comes to successfully scaling DM, with the exception of multi-site decentralized manufacturing within one private actor system (e.g. spare part production by Shell, Caterpillar, Siemens, etc.). Further research and exploration is needed on a number of topics:

ON THE PROMISES AND IMPACTS OF DM:

What are the real economic costs of DM versus traditional manufacturing models in a globalized world in crisis? Since DM is a relatively new technology, its long-term economic impact is yet to be fully understood. This requires a comprehensive and nuanced approach that takes into account a variety of factors, including production costs, energy consumption, labor costs, supply chain costs, environmental costs, and feasibility. To evaluate the long-term economic costs of DM, it is essential to consider its broader economic impact, including its impact on employment, economic growth, and innovation. It is also crucial to consider the potential social and environmental benefits of DM and how they contribute to long-term economic growth.

What is the ecological impact of DM? Comparative studies are needed with a view to understanding the circumstances in which DM is environmentally beneficial and those where it is not. Such studies should measure the ecological footprint of different approaches and show their impact with data.

What is the social impact of DM, and how can that be quantified? This question is particularly relevant to public and aid-funded procurement – an approach is needed to allow social surplus created to be taken into account in the evaluation of competitive bids. Ideally a holistic approach taking into account environmental and social factors could be developed, to allow procurement to be a core part of the impact strategy of organizations serving the public good.

How does scaling affect DM initiatives' impact? Are they aware of potential negative, unintended and indirect impacts? How can we better measure the impact of DM in the Global South? Overall, there is still insufficient evidence and baseline data to systemically measure and evaluate the impact of DM in the Global South, as is the case in most humanitarian and many other similar innovations.

ON STRATEGIES, INITIATIVES AND POLICIES:

How can DM be integrated into broader development strategies and initiatives in the Global South? In the last decade, more and and more development strategies and initiatives in the Global South have focused on innovation and entrepreneurship, while many remain committed to vocational training and capacity development. Development agencies should explore potential intersections of DM and existing programs and projects, and with their procurement policies.

How can international development better understand which local DM ecosystem needs what kind of support in the vastness and diversity of the Global South? The UNDP Accelerator Labs for example realized that they needed local nodes to understand local ecosystems and could accelerate development that way, by celebrating the diversity and plurality of grassroots innovations. Could a similar approach work for stabilizing and scaling DM?

What are the most effective strategies for promoting the adoption of DM in the Global South, and how can policymakers and other stakeholders support these efforts? The most successful form of DM is the decentralized production of spare parts at multiple production sites of global industry players. One potential way of leveraging this success is for these players to support trained local staff if they want to venture into starting their own businesses, to which the multinational corporation could then outsource the manufacturing of specific parts, which would in turn support the development of a local DM ecosystem. Policymakers could support this with legislations for DM, such as Start-up Acts, which give tax breaks and reduced import fees to start-ups in several countries in the Global South already.

How can standards agencies provide more cost-effective support for smaller manufacturers, informal networks and innovative individuals to gain affordable certification advice early on? Rapidly produced PPE and medical equipment was also rapidly certified by different standards agencies during the Covid-19 pandemic. How can this be reproduced without the threat of a global pandemic? One suggestion is for government bodies to set up “pop up” certification centers or advice centers to provide quick help and testing in situations where there are no alternative certified products available, or where they are unaffordable for most end users.

ON SCALING DM:

What are the pathways to successful scaling of DM initiatives? Can a typology of DM models be further developed, including context, technologies, and other variables, and success factors mapped against it? In which industries and contexts is DM most useful? Such a typology would allow the generation of more meaningful conclusions on what is most likely to work in what situation, and subsequently, support scaling efforts.

What should a DM network look like? What type of actors, networks, technologies, infrastructure and so on are required - and at what level are those most effectively provided?

What approaches to quality control are more successful in what contexts? A complex set of factors including industry, product complexity, level of variability in raw materials, manufacturing process and product design, and the regulatory environment are likely to influence quality outcomes – is it possible to develop best practice guidelines for different situations?

What multistakeholder business models are emerging that might benefit scaling DM? Open innovation as a service is one emerging business model, as companies want to tap into talent everywhere. However, who would host a multistakeholder open innovation service provision network and/or database? One important question to consider is whether such business models are extractive in nature.

Can one scaling framework cover the whole of the Global South? Or are regional or local frameworks needed to avoid the development of projects that are doomed to fail? Experimentations in difficult sectors such as healthcare, where regulations and standards are explicably high became apparent in the Protege BR and Makers' Asylum cases, but with different outcomes: in India, experimentation with a locally developed and frugal, low-cost active respirator was stopped and the key take-away was that testing facilities only exist outside of the country and should be established within; in Brazil, it essentially led to the adoption of open protocols adequate to Brazilian health sector regulations. This shows that the same approach can have very different results in different contexts.

ON SUPPORTING COLLABORATION:

How can traditional manufacturers, DM organizations, and makers be brought together to collaborate? Can the clash of values (e.g. openness and sharing vs closed source blueprints, collaboration vs competition) and other major gaps be bridged through exchange? "Distributed manufacturing" exists in a traditional way, there are SMEs on the ground manufacturing products. However, there is a disconnect between innovative, inventive, experimenting makers (cottage industry) and traditional manufacturing, especially at a medium scale.

How accessible is open knowledge to those who could benefit from it? As open hardware and open source software are seen as approaches that can support DM, it is also important to understand how open knowledge might contribute to scaling DM. However, open does not necessarily mean easily accessible for everybody, and there is a need to understand what the biggest obstacles for practitioners are and how they can be overcome. There is existing literature looking into this question, but key points need to be verified and edited into recommendations.

APPENDIX 1.

CASE STUDIES

1. BRAC
2. KIJENZI
3. NEPAL 3DP
4. BENEFICIAL BIO
5. MAKER'S ASYLUM
6. MOTIV
7. PROTEGE BR
8. ROBRIES
9. WAZI VISION

BRAC

FACTS & FIGURES

Sector
WASH & Health

Founding Year
1972

Locations
Multiple factories in Dhaka & Cox's Bazar, Bangladesh

Owners
non-profit organization

Link
https://brac.net/

> "Procurement should play a much deeper role in terms of the equity mission of NGOs.
>
> Kuldeep Aryal

CONTEXT

BRAC is the largest NGO in the world by number of employees. Founded in Bangladesh, it still has a strong presence there supporting people living in poverty across the country as well as the Rohingya refugees from neighbouring Myanmar, concentrated in Cox's Bazar. The FT Hub supported a pilot undertaken by BRAC Social Innovation Lab to aggregate demand from within different parts of BRAC, allocate that demand to local manufacturers and support them to meet the quality standards required, and explore how to adapt the NGO's systems to be able to procure smaller quantities from multiple manufacturers.

Estimates suggest that up to 80% of the global humanitarian budget is spent on buying and moving products[1]. BRAC's efforts to ensure that the way this money is spent contributes to their overall mission is pioneering and deserves to be widely studied.

MOTIVATION

Social Surplus: BRAC's mission is "to empower people and communities in situations of poverty, illiteracy, disease, and social injustice". The primary motivation behind using distributed and local manufacturing is for the money spent on procuring goods to contribute to that mission not only through the products bought but also through the people funded to make them.

Rapid Supply: An additional benefit is reducing the lead time for remote locations such as health posts to get the products they need.

CUSTOMERS & REVENUE STREAMS

BRAC: BRAC's own programs were the customers for the locally produced products, which focussed on PPE and WASH items (including soap) for the pilot.

PARTNERS & ECOSYSTEM

BRAC: the pilot project was a collaboration between a number of different departments and programs of BRAC, including the Social Innovation Lab, the Humanitarian Crisis Management Program (HCMP), Central Procurement, the WASH unit, and BRAC logistics (including the WASH warehouse & Health warehouse).

Fab Lab SAU: The Fab Lab at Sher-e-Bangla Agricultural University was a key part of the ecosystem, acting as a quality control hub for some products and providing access to additional equipment for small maker businesses.

Local Manufacturers & Maker Spaces: a variety of small and medium manufacturing enterprises and maker spaces in Dhaka were engaged to make different products.

[1] Moshtari et al (2021)

SUPPLY CHAIN

Locally available materials: the majority of materials needed for the different products made were available on the market locally to the production sites (in either Dhaka or Cox's Bazaar). A small proportion of the materials needed in Cox's Bazar could not be found locally and were procured from Chittagong, the port of import.

BRAC Logistics: existing warehouses and transport mechanisms were used for storing and moving both materials and finished goods.

CHALLENGES FOR SCALING

Procurement policies & contracting process: a range of challenges emerged, ranging from legal requirements for suppliers to BRAC that were in some cases difficult for small companies to meet (solved by creating sub-contract arrangements), to the imposition of different (higher) quality standards for locally produced goods than used for international contracts. A lot of work remains to be done on contracting processes.

Lack of measures for social surplus: there are no measures or formulae to guide calculation of the additional benefit of procuring locally manufactured products.

Quality: a number of product quality issues were experienced, particularly as efforts were made to move production out of Dhaka and closer to the point of use. In the capital, using Fab Lab SAU as a quality control hub was successful.

ENABLERS FOR SCALING

Long term crisis: For humanitarian organizations to procure locally made products, it is helpful when a response moves from the emergency phase into a protracted crisis, and agencies need to think about localisation as part of their longer term strategy (although they should not wait for this).

Development focus on manufacturing: there is a renewed emphasis on the role of technical skills and the light manufacturing sector in development strategy.

Existing logistics system: it was very helpful to be able to tap into the existing BRAC logistics system.

Technological development: Future developments are expected to facilitate the scaling of DM, including Artificial Intelligence (the use of image analysis for quality control) and the development of platforms to manage procurement & quality in DM.

SCALING OUTLOOK

Mainstreaming: Efforts are ongoing to mainstream the use of distributed and local manufacturing for procurement requirements within BRAC. Localisation of supply chain and local manufacturing has become a central part of the innovation strategy for HCMP-WASH.

System Change: this is a radical departure from the traditional procurement approach of the humanitarian sector, and concentrated effort will be needed over a period of time to ensure it can reach its potential.

KIJENZI

FACTS & FIGURES

Sector
Flexible Manufacturing

Founding Year
2019

Locations
Kisumu, Kenya

Owners
John Gershenson & Ben Savonen

Link
www.kijenzi.com

> "The success of a 3D printing business will be based on the ratio of time spent engineering to manufacturing.
>
> John Gershenson

CONTEXT

Kijenzi is a social enterprise using 3D printing to put localized, distributed manufacturing to work for institutions who do the public good. The initial idea was to make anything people asked for - but they gradually learnt that this made costs too high. The challenge was to assess which products would be needed in higher volumes, and how to find the customers who needed that particular thing.

Kijenzi was supported by the FT Hub in 2021-22 to test key aspects of their model and how it could be adapted from a single node to a hub-and-spoke model. A satellite was set up in Mombasa by someone who had previously worked at the main hub in Kisumu. This experiment did not generate enough revenue to cover its costs but has informed the current view of scaling models. Kijenzi has always put a strong emphasis on quality and is working towards ISO 9001 certification.

MOTIVATION

Product Availability: the founders' motivation was to make things (final products and components or spares) available in places and volumes where they are not currently found. They saw a huge gap for local suppliers of quality products.

CUSTOMERS & REVENUE STREAMS

Medical spare parts: Kijenzi's initial focus was on spare parts for medical devices. The need is there and they were able to provide the right quality to address many of them – but the engineering of each different part took so long that it made parts too expensive.

Bridge manufacturing: Production orders Largely bespoke products. Kijenzi have found this to be a profitable revenue stream but not consistent enough to base a sustainable company on – it works better as an add-on to a more stable production base.

Prosthetics & Orthotics: – can do it for roughly the same price as existing methods but much faster, so the children need fewer visits to the hospital (especially important for families that live far away). On some products costs are lower. Patients tyically get the device within 24-48 hours.

PARTNERS & ECOSYSTEM

Universities: from its origins in Penn State University research projects to collaborations with Kenyatta University, universities have been important partners for Kijenzi, particularly for recruitment (working with students who then become interested in joining the team).

Hospitals & Cure International: both on medical spare parts and with the development of an effective workflow for prosthetics & orthotics, healthcare organizations have been a key partner.

Local manufacturers during COVID-19: large volumes of PPE were produced by a network of local manufacturers making different components, with Kijenzi doing assembly and quality control.

SUPPLY CHAIN

Direct import: Kijenzi directly imports 3D printer filament, from Europe and China. There were some challenges setting up this process but it now works smoothly.

CHALLENGES FOR SCALING

Product diversity: low levels of repeat production mean high engineering costs per unit of revenue. A catalog of standard products would lower costs and be useful for sales but with the existing regulatory framework in Kenya this would be too expensive to work.

Lack of ecosystem: Kijenzi wants to be a manufacturing company, but has found itself playing other roles due to the lack of an established ecosystem. They believe the whole sector will become more viable when there are more specialised players who get to be very good at one step in the value chain.

Access to funding: scaling involves developing new models as they grow – something most investors avoid.

Network overheads: based on experiments to date, Kijenzi believes the costs of managing complexity (in particular to maintain quality) will grow faster than revenues initially as they move from one node to several.

ENABLERS FOR SCALING

Business Model Experimentation: the financial ability to trial different versions of the business model has been crucial in enabling Kijenzi to get to where they are.

Research mindset: the founders credit their academic backgrounds and interest in research with having helped them through the process of testing different approaches - but caution that at a certain point it becomes more of a hindrance.

SCALING OUTLOOK

Seeking Investment: additional funding is now being sought to develop the next iteration of the business model.

Mass Customization: Kijenzi's focus for scaling is the mass customization of prosthetics & orthotics.

NEPAL 3DP

CASE STUDY 3

FACTS & FIGURES

Sector
Flexible Manufacturing

Founding Year
2015

Locations
Nepal

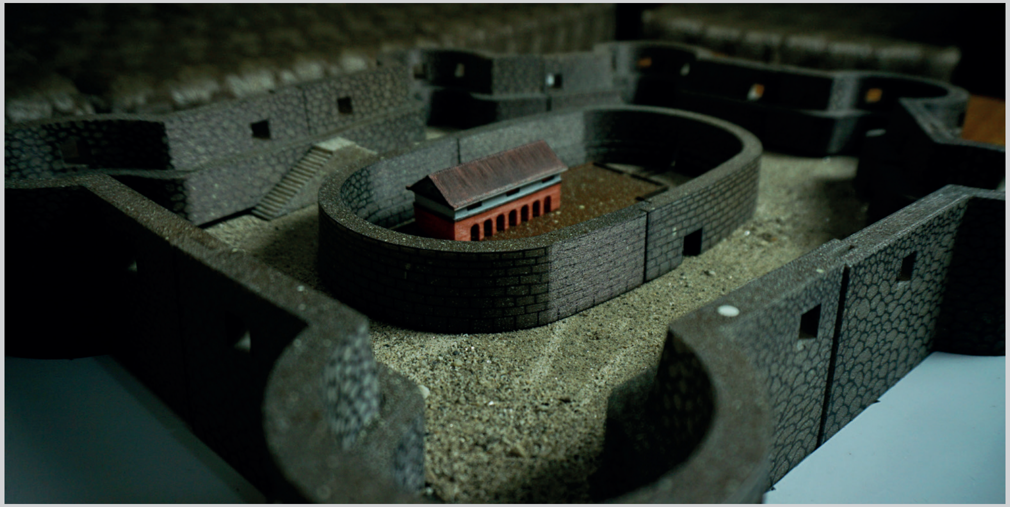
Owners
Various

Link
www.zenertechnp.com

> Tens of thousands of locally made improved cookstoves are installed across Nepal every year, made by sand-casting using a 3D printed pattern.
>
> Ram Chandra Thapa

CONTEXT

As a landlocked country in the Himalayas, Nepal has many supply chain challenges. The growth of 3D printing and other forms of digital manufacturing there offer unique insights into the potential for scaling DM from a specialist NGO-deployed technology into a thriving commercial sector. The 3D printing sector in Nepal was established after the earthquake response and has experienced significant growth, going from just a few printers in 2015 to over a hundred by the end of 2022. Although this case study title refers to 3D printing, in fact the digital manufacturing sector has expanded beyond that in Nepal to include laser and plasma cutting.



MOTIVATION

Disaster Response: 3D printing was first introduced to Nepal in the wake of the 2015 earthquake, in order to support with supply chain challenges and the massive need for rebuilding.

CUSTOMERS & REVENUE STREAMS

3D Printing services: The sector serves various industries, including architecture and design firms, art and craft manufacturers, metal casting factories, injection molding factories, product development start-ups, and universities.

3D Printer Sales, installation & training services: As uptake of the technologies increases, it creates a market for organizations to invest in building their own capability.

PARTNERS & ECOSYSTEM

Humanitarian Organizations: Field Ready and World Vision's Innovation Lab were instrumental in bringing 3D printing to Nepal and creating the early conditions for its uptake.

Zener Technologies: This private company founded by a former employee of Field Ready has been in the vanguard of the development of the private sector, currently offering 3D printing and laser cutting services as well as selling 3D printers.

Local Industries/SMEs: digital manufacturing processes offered as a service by Zener Technologies and others have now become an established part of the manufacturing processes of many local organizations, including artisans using centuries old lost-wax and sand-casting processes using 3D scanning and printing to create patterns and moulds of different sizes.

Universities and Innovation Centre: Government-funded education and business organisations are now helping to spread digital manufacturing technologies, including outside the capital.

SUPPLY CHAIN

Direct import: There is now a well established supply chain ecosystem between Chinese manufacturers and Nepali service providers for raw materials, 3D printers and other equipment, and spare parts.

CHALLENGES FOR SCALING

Raw Materials: High cost of materials such as 3D printing filament, acrylic sheet and wooden board due to high import tax (up to 50%) and high shipping cost (up to $10 per kg)

Unreliable electricity supply: power blackouts interrupt the printing process and affect the quality of the finished product

Skills: Digital manufacturing is a skill intensive business as it requires high level design and post-processing skills. Zener Technologies typically needs to train a new recruit for six months before they can work independently – a high cost for a small business.

Material limitation: Current 3D printing is limited to plastic, rubber and resin materials. Metal 3D printing can open new markets in dental, medical and precision spare parts.

ENABLERS FOR SCALING

Donor support: early investments by donors including FCDO were instrumental in allowing digital manufacturing to scale in Nepal by reducing the investment risk, for example the UKAID COVIDaction award enabled the introduction of plasma cutters.

Technology showcasing: The early 3D printing work by NGOs was done in open labs, so those who were curious about the technology could see for themselves how it worked. This is vital to spread its use by existing industries – the manufacturers need to see it work to understand what part it could play in their production processes.

Private sector investment: initially companies offering digital manufacturing services started to invest in their own equipment and now companies in other industries are building their own capabilities.

SCALING OUTLOOK

Expansion of local capabilities: As traditional companies start to bring digital manufacturing capacity in-house, the specialist DM service companies are moving into more frontier technologies. The next milestone in the 3D printing sector of Nepal would be introducing Nepal's first metal 3D printing.

Investment in commercial 3D printer filament production would likely accelerate growth in the sector and could cater to the needs of small makers in the region for Nepal, Bhutan, Bangladesh and India.

BENEFICIAL BIO

FACTS & FIGURES

Sector
Biotechnology

Founding Year
2019

Locations
Labs in Oxford (UK), Yaoundé (Cameroon); projects in Ghana, Ethiopia, Kenya, Chile, Argentina

Owners
Dr. Jenny Molloy (Beneficial Bio Ltd, UK), Dr. Thomas Mboa (Mboalab Biotech, Cameroon)

Link
https://beneficial.bio

CONTEXT

Beneficial Bio is a network of biotech social enterprises run by biologists that provides tools and services to produce enzymes in the Global South. Enzymes are widely used in various sectors such as medicine, agriculture, textile production, waste reduction, food industry, and petrol sector. Importing and shipping enzymes and the initial reagents is challenging, but Beneficial Bio labs offer local manufacturing hubs that provide effective delivery tracking and payment options, to address such challenges.

> "Distributed making is the only way that we can overcome the shipping and importation and customs barriers that really add to the time and the cost of reagents. Because we are distributed it means we need to have a system in place where we can easily share protocols and knowledge within the network, but also gather data from all of the nodes on demand, production, quality and customer feedback.
>
> Dr. Jenny Molloy

MOTIVATION

Equitable access to technology: Biotechnology research and innovation are used in health, agriculture and the energy sector (petrol production), but it is unevenly distributed in favor of industrialized countries. Beneficial Bio aims to bridge this divide and provide equitable access to technology.

Equitable skills distribution: Enzyme expression and production has been around since the 1980s and is complex for biologists. Enzyme expression is an unevenly distributed skill. Access is democratized through capacity development, stimulating innovation and reversing brain drain.

Circumventing financial and tax burdens: Currently, fluctuating foreign exchange rates and high import taxes negatively impact the ability to import enzymes to many LMC, thus, Beneficial Bio aims to have at least one enzyme-producing node in each customs union.

CUSTOMERS & REVENUE STREAMS

Market-specific retail: Beneficial Bio hubs generally follow two approaches: develop products first, understand markets later, or explore markets, then develop projects. Nodes are entering different sectors at their locations: leather production (Ethiopia), agriculture (Kenya, Ethiopia), medical testing and research (Cameroon, Chile, Argentina). The Ghana node is researching local markets.

Education: Beneficial Bio offers an enzyme expression masterclass as part of the support package to hubs, most often funded by external grants, designed so that self-replicating through living cells is possible.

Testing and research: Beneficial Bio labs provide testing and research, both as part of research / project consortia, and to external clients.

PARTNERS & ECOSYSTEM

Network of independent nodes: pilot projects in Cameroon became a main node of the network, producing six different products; in Ghana focuses on market research and developing a market; in Ethiopia and Kenya striga-resistant sorghum is developed, and a lab is being built in Kenya to provide reagents for start-ups.

The organization has **memorandums of understanding** with local governments and international donors.

The organization is also part of **regional and international networks**, such as Global Open Science Hardware, Africa OSH, African Makerspace Network, Just One Giant Lab and Global Innovation Gathering .

SUPPLY CHAIN

Supply chain challenge: Enzymes are proteins that catalyse reactions (e.g. PCR, Polymerase Chain Reaction), but are not readily available in most LMC and typically need to be shipped on ice, posing challenges to the supply chain.

Local production approach: Enzymes can be reproduced reasonably easily in labs using the same techniques, e.g. creating enzymes that reduce garbage, or that break down collagen and keratin in animal hides during leather production.

Advantage: Enzymes are able to catalyze over 5,000 types of reactions, making them a key ingredient in the refining raw material stages in many industries and therefore offering opportunities for many industries in LMC.

CHALLENGES FOR SCALING

Infrastructural challenges: Electricity and internet connectivity are still not stable, especially not in Cameroon.

Brain drain: Not only is it hard to find trained and experienced staff for Beneficial Bio nodes, but trained staff also sometimes leaves the company.

In-person tech transfer: During the COVID-19 pandemic it became apparent that the required tech transfer is often very hands-on and easier in-person than online.

ENABLERS FOR SCALING

Funding: funders who were willing to accept that a lot of the structures are experimental and were ready to fund meetings

Automation and offline functions: Automating packing lists, commercial invoices and other shipping documents, and quality assurance through shared checklists. E.g. Survey Stack allows all nodes to employ the same quality control regime and it is used as a training tool for new labs joining the network.

Quality control and management system: The Cameroon pilot node had a specific Quality Manager and staff was trained in quality control (essential to assure that product shipped to users functioned). ISO9001 compliance was achieved that meets international standards and invokes trust from customers.

Partnerships on the meso level: with local governments and customs and MoUs between the organization, its nodes and the government and international donors were useful.

On the global level: international networks enable the leaders of the local nodes to understand their own role better through an outside perspective.

SCALING OUTLOOK

Business model design on the network level: by connecting the different nodes to the global biotech ecosystem while recognizing that “the Global South” is a diverse set of places and contexts. On the organizational level: Beneficial Bio will also restructure its company, raise more and potentially different funds, and retain the people it identified as being able to take Beneficial Bio further.

Scaling through compliance with standards: In the future, it aims to become ISO 13485 compliant to meet the quality standard required for diagnostic reagent production and thus open up the higher-margin and impactful diagnostic market, enabling the network to raise sufficient funding for operations and growth, but it requires significant investment to achieve in the first place.

MAKER'S ASYLUM

CASE STUDY 5

FACTS & FIGURES

Sector
Healthcare

Founding Year
2020[1]

Locations
Network of manufacturers across India co-ordinated by Maker's Asylum in Goa

Owners
Richa Shrivastava, Vaibhav Chhabra

Link
https://makersasylum.com/

> "When we were writing the goals for the crowdfunding campaign, one of us said: let's say we'll produce 1,000 face shields. Then someone else asked, why not 10,000? We had no idea if we could do it, but we did, and by building a distributed network of partners and open source design, we ended up producing more than a million!
>
> Richa Shrivastava

CONTEXT

Makers Asylum is a community-based, open makerspace in India normally engaging in educational projects. During the Covid-19 pandemic they quickly realized that they could help with the personal protective equipment (PPE) shortage, and built networks of makers, manufacturers and hospitals; including experimentation with the local and distributed production of more than 1 million face shields, low-cost powered air purifying respirators (PAPR) and oxygen concentrators, as well as a decentralized network to repair oxygen concentrators that broke after arriving in India.

MOTIVATION

Supply chain breakdown: During the first wave of COVID-19 in India, many frontline workers struggled due to a lack of PPE. Online maker fora started sharing open source designs and Maker's Asylum launched a crowdfunding campaign to start producing such equipment with their machines and locally available materials. Using a social entrepreneurial model, these were sold for around the cost of production.

Machines lacking and not appropriate for the context: During the second lockdown, Open Source Medical Supplies (OSMS), a curated open-source design library predicted that there would be an upcoming oxygen crisis. Thus, Maker's Asylum teamed up with local divers to design low-cost machines and kicked off a repair café network to fix imported machines that did not function in the local environment.

CUSTOMERS & REVENUE STREAMS

During the first wave, the team focused on PPE and experimentation with low-cost machines:

- **Crowdfunding campaign** was organized to produce PPE for frontline workers.
- **Procurement** also became a source of revenue as hospitals bought necessary equipment from them. The pricing was set low, to enable access but cover basic costs

During the second wave, the team focused on the oxygen shortage:

- **Project-based EU funding** was received to kick-off a decentralized repair ecosystem for oxygen concentrators that broke down after arriving in India
- **Research funding:** together with the University of Cambridge, funding was acquired for quality assurance for open source hardware

[1] Maker's Asylum was founded in 2013, but the M19 initiative was created in response to the COVID-19 Pandemic

PARTNERS & ECOSYSTEM

Maker's Asylum is highly network-oriented, focusing on collective approaches. In addition to the community in their makerspace, they built **regional / national (meso-level) project-based networks of partners**, including:

- hospitals e.g. AIMES in Delhi to experiment with a locally designed and cost effective respirator and oxygen concentrator
- local manufacturers with the right certifications
- decentralized network of repair cafés
- scuba divers for transferrable technologies and skills on oxygen concentration

And are also members of **international networks:**

- Pre-COVID-19: partnerships with universities worldwide (France, US)
- The Open Source Medical Supplies (OSMS) newsletter was a source of inspiration both for PPE and predicting the oxygen shortage
- International maker networks, e.g. a Chinese maker shared zeolite and tools

SUPPLY CHAIN

Experimentation with local materials: due to the unavailability of PPE and materials, experimentations were conducted with 3D printing and MDF, but were rejected by doctors. The focus shifted to locally available materials such as foam boards, and existing facilities with laser cutters. Injection molding was used for larger quantities.

Makers sharing during lockdown: technology and knowledge transfer took place as the team experimented with scuba divers' tools for oxygen concentrators (compressors were available locally) and zeolite was sent from China by a maker.

CHALLENGES FOR SCALING

Regulation: healthcare regulation is extremely important, but it also hinders scaling of locally produced, low-cost machines as the legalities of responsibility are unclear

Quality assurance: EU funding allowed exploration of the quality assurance of open source hardware, and to expand quality assurance from "the best quality" to the "most accessible quality level in the given, local context" (balance of quality and need)

Lack of testing centers: there is currently no infrastructure for testing machines designed and manufactured in India, labs are only available outside of the country.

Lack of skills: especially when it came to healthcare-specific repairs of existing oxygen concentrators, thus, local people needed to be trained

Supply chains: especially during the lockdowns, there was no supply chain for a key material (zeolite) and had to be sent by a private person from China.

Lack of a map with local machines: it is difficult to distribute manufacturing without easily accessible information on where machines for DM are available (e.g. laser cutters), thus, this had to be mapped

ENABLERS FOR SCALING

Open hardware networks: OSMS and other international open hardware networks sharing blueprints, and reports forecasting needs

Creativity and experimentation: instead of 3D printing or MDF (not useful in healthcare setting because too absorbent), a locally widely available material was used (foam board), or moving from 3D printing to laser cutters to injection molding

Crowdfunding campaign: allowing for initial funding and for the team to bring more makers on board India-wide

Partnership with hospital: Although the project wasn't fully realized due to regulations, the fact that a hospital engaged in experimentation, allowed makers to locally/frugally design and produce cheaper machines that were necessary

Network building: local networks of makers, manufacturers, healthcare workers and hospitals were crucial for the distributed manufacturing and sharing of PPE

Open source design: as laser cutting machines were available country-wide, these were connected to local maker communities, and a small, self-sustaining network of networks was created.

Knowledge and tools transfer: locally specific knowledge and technology transfer took place as divers' tools were re-designed into oxygen concentrators on Goa

SCALING OUTLOOK

Return to Business-as-Usual: manufacturers in the M19 network have gone back to their pre-pandemic lines of business. The network is no longer active as an entity.

MOTIV

FACTS & FIGURES

Sector
Creative Industry / Making / Arts & Craft / Cottage Industry

Founding Year
2019

Locations
Kampala, Mbarara, Gulu, Jinja

Owners
The Innovation Village (CEO CK Japheth)

Link
https://motiv.africa

> "The space is not enough for all the makers and creatives out there – so let's bring MoTIV to the communities and find out what their challenges are!
>
> Ronald Tumuhairwe
> MoTIV Platforms Lead

CONTEXT

MoTIV (Makers of The Innovation Village) Africa was founded in partnership with the MasterCard Foundation and in 2019, opened its makerspace in Kampala. Currently, this is the biggest makerspace in East Africa with six warehouses. Through its network of hubs in Kampala, Mbarara, Jinja and Gulu, MoTIV is helping to create a more diverse and resilient manufacturing sector in Africa connecting suppliers, producers and customers, and thus can respond quickly to changes in demand and market conditions, and drive positive social and economic change in the region. Its Virtual Factory Network is a platform for cottage industry entrepreneurs, raw material suppliers, training centers, and market connectors and agents, sharing opportunities and exchanging information.

MOTIVATION

MSMEs as employers: Uganda's private sector is dominated by Micro, Small and Medium Enterprises (MSMEs) comprising approximately 1,100,000 enterprises and employing approximately 2.5 million people equivalent. 77% of Uganda's population is under 25 years. and the MSME sector is a key driver of employment, with a high prevalence of informal MSMEs employing over 83.5% of youth.

"Virtual Factory Network" (VFN) is a crowdsourced platform that maps cottage entrepreneurs to provide data for accurate innovative programming. On this platform, entrepreneurs, start-ups and the public share opportunities around market linkages, financing, talent exchange and research. A first use case of VFN was the production of masks during the COVID-19 pandemic in different locations.

CUSTOMERS & REVENUE STREAMS

MoTIV aims to support the growth and development of the tech and manufacturing sector in Africa, promoting innovation and supporting local businesses.

Entrepreneurs and start-ups: range of services and activities are provided to support the creative industry in Uganda, such as maker and co-working spaces, training and development programs, and access to funding and mentorship opportunities. Makers pay a small fee for using the space and the machines, and a commission on loans granted by MoTIV for purchasing raw materials.

Donors: Programs and projects with support from donors, most importantly Mastercard Foundation's Young Africa Works program.

Retail: The MoTIV Marketplace Omwoleso is a physical and digital space to showcase the products created by MoTIV's cohort of artisans, makers, and innovators and provides market connections and investment opportunities.

PARTNERS & ECOSYSTEM

MoTIV operates within the Ugandan entrepreneurial and innovation ecosystem. Its specific ecosystem comprises:

Public institutions such as Vocational Training Centres, policy makers, government agencies such as the One Stop Centre for Investment at Uganda Investment Authority (UIA)

Private sector companies such as raw material and logistics providers, retail shops, micro insurance and micro credit institutions, and digital marketers,

Civil society organizations such as Uganda Small Scale Industries Association,

International development partners such as Mastercard Foundation.

SUPPLY CHAIN

Challenge of materials availability: Access to affordable, quality-assured raw materials poses a challenge for most MSMEs in Uganda. MoTIV tackles this challenge through its Virtual Factory Network (VFN), which maps and connects suppliers, producers and customers. A country-wide network of local VFN agents helps offline stakeholders join the online community. Access to high quality raw materials is a challenge for most artisans and makers in Uganda. This is tackled by providing:

- sset-based finance: VFN provides access to asset-based finance by granting credits from MoTIV to makers, so they can purchase raw materials;
- Quality control capacity development: to enable producers to ensure quality control; a database of suppliers is also shared with VFN members.

CHALLENGES FOR SCALING

Lack of professional capacity and policies: in terms of infrastructure, finance and regulation, a lack of support is a general challenge for the whole Ugandan innovation ecosystem. This results in the lack of professional capacity to produce quality products and services, as well as inadequate policies

Lockdowns: major challenge to MoTIV's operations, as running costs continued, while less revenue could be made - this was the same for most of MoTIV's target group, many of whom had to close their businesses

Maintenance and repair: a challenge for all distributed manufacturing as purchased machines that broke during the lockdowns in any node except for Kampala were hard to repair and maintain because of lack of spare parts.

High costs: expensive internet connectivity, a lack of affordable, easy-to-use, #offlinefirst software for administration (e.g. an ERP system), and the related lack of quality assurance posed challenges even for the relatively easy and straightforward project of manufacturing masks during COVID-19 in a distributed manner.

Lack of human capital: VFN's small team (3) does not have capacity for tasks such as further development of the database and website; or awareness raising, which would be especially important as DM is a new concept for the makers and artisans communities, who do not yet fully grasp the benefits it offers them.

ENABLERS FOR SCALING

Funding: MoTIV has received funding from MasterCard Foundation and others, which is a big enabler for all of its operations.

Mobile Money is one important enabler for scaling distributed manufacturing, as many Ugandan entrepreneurs and micro enterprises do not have a bank account.

Digital literacy and the availability of mobile internet connectivity are strong enablers, as are SMS- and USSD-based mobile appliances.

Human agents: A network of human agents, who help suppliers, producers and consumers go online, is another strong enabler for the Virtual Factory Network.

SCALING OUTLOOK

Growing business ecosystems: MoTIV plans on continuing to grow business ecosystems that create jobs, have vibrant local art markets, and create linkages for creatives to markets at a regional and international scale.

Legislation: Discussions to facilitate the provision of a Start-up Act have been started within the ecosystem.

Database and website development: More research, campaigning and further development of the database and website are needed. The team applied for funding through grants to scale the Virtual Factory Network (VFN), while they also try to grow the revenue of the VFN through commissions for credits and consultancies.

PROTEGE BR

FACTS & FIGURES

Sector
Healthcare / PPE

Founding Year
2020

Locations
250 initiatives mapped in all regions of Brazil

Owners
Olabi

Link
https://protegebr.org/

> “As the first wave of COVID-19 started hitting Brazilian hospitals, we saw the opportunity to organise what we called “productive anxiety” in more appropriate ways.
>
> Gabriela Agustini

CONTEXT

Protege BR was a collaborative network organizing the production capacity of makerspaces and small-scale manufacturers supporting healthcare professionals in the wake of the COVID-19 pandemic in Brazil. Protege BR accelerated collaborative efforts between local initiatives, places to test their products, and distribution; and was a platform through which local initiatives in all regions of Brazil would share and access designs, know-how and production processes and coordinate supply chain information.

MOTIVATION

Information and connecting actors: The network emerged from the perceived need to organize information and support production capacity of local actors interested in contributing to addressing the COVID-19 pandemic, helping them gain agility and achieve quality

Supporting distributed approach: different actors performed diverse roles: manufacturing equipment (3D printers and laser cutters) were used to prototype and manufacture PPEs; as mediators and facilitators they connected PPE manufacturers with organizations and communities in need; or promoted public debate on intellectual property issues, liability, regulations and open standards.

Establishing cooperation: Protege BR created bridges of cooperation between high-end research facilities and manufacturers on a local scale.

Promoting open protocols and open source specifications: The platform articulated the development and sharing of open protocols and open-source specifications for healthcare equipment.

CUSTOMERS & REVENUE STREAMS

Funding: Google funded the set-up of the online platform, initially designed to map the emerging local production of medical equipment in all Brazilian regions.

Healthcare: The main customers and beneficiaries were hospitals, public health authorities, and other health-related organizations such as emergency care units.

Charities: the project helped charities organize pandemic response efforts in local communities, such as the Favela da Maré in Rio.

Diverse revenue configurations: the initiatives on the platform had funding from grants, public procurement, donations and retail.

PARTNERS & ECOSYSTEM

Diverse network building: Protege BR organized an emerging network of makerspaces, small-scale manufacturers, municipalities, and universities.

Academic support: PUC university (Rio de Janeiro) provided access to its research facilities and to prototyping/manufacturing laboratories.

SUPPLY CHAIN

Lack of initial coordination: Due to a lack of coordination, makers rushing to address the effects of the pandemic would often incur wasteful or inadequate production, e.g. replicating the manufacturing of valves for respirators from Spain which were inappropriate for the respirators available in Brazil, and as a result, useless pieces of plastic were made.

Mapping and open protocols: mapping of distributed approaches reflecting the diversity of local conditions and institutional arrangements, and providing public documentation about the manufacturing of face shields, protection goggles, respirators, N95 masks, acrylic boxes for intubation, surgical masks, surgical aprons, cloth masks, video laryngoscopes and CPAP masks, also helping manufacturers understand how best to prepare for the approval processes.

Outcome: PUC 250+ initiatives between civil society volunteer groups, makerspaces, university labs and technical institutes, regional business associations, small-scale manufacturers, a nationwide industry organisation, and others - in all regions of Brazil and the manufacturing of almost one million products.

CHALLENGES FOR SCALING

Domestic infrastructure and logistics: these are known to be imperfect, but were temporarily disrupted and worsened by the pandemic.

Global pricing: internationally, barriers include competitive imbalances in prices.

Lack of cooperation: For small organizations, lack of cooperation between local actors and complex regulations make producing healthcare equipment unfeasible.

Hotspots of incidences and urgency: high incident numbers centralized needs in places where it was hard to get products into, and created the necessity to produce and distribute materials on a mass scale, resulting in sudden demands for PPE. However, due to lockdowns, contacting people in those territories was complicated.

ENABLERS FOR SCALING

Overcoming everyday obstacles: The sudden demand for PPEs in practically every region of a country as large as Brazil, contrasted with the difficulty in sourcing such goods from international markets at that point, provided enough motivation to overcome the usual obstacles to distributed manufacturing.

Certification developments: The urgent need for equipment pressured authorities to clarify specific standards and regulatory frameworks for certification and approval. Adoption of open protocols adequate to Brazilian health sector regulations following experimentation with large public hospitals.

Skilled actors: makerspaces, fablabs, and small-scale manufacturing facilities stepping in early to face the sudden spiking demand for basic healthcare equipment, experimenting with novel approaches to use skills and capacities to help mitigate the effects of the rapidly spreading disease.

Repurposing installed capacity: large public hospitals and specialized manufacturers were connected, helping to repurpose installed capacity to produce healthcare equipment. The University of São Paulo created an open-source respirator that could be produced in two hours and cost 10 to 15 times less.

Prior contact between organizing nodes: Olabi, a nonprofit, maintained a makerspace in Rio de Janeiro from 2014 until 2020 and had built rapport with many maker initiatives around the country, creating trust and accelerating collaboration.

SCALING OUTLOOK

Almost 1,000,000 pieces were manufactured in 250+ initiatives nationwide, but as the demand for healthcare equipment was re-balanced based on the capability of large-scale manufacturers and the reinstatement of imported goods, Protege BR ended.

ROBRIES

FACTS & FIGURES

Sector
Furniture made with recycled plastic

Founding Year
2018

Locations
One plant in Surabaya, Indonesia

Owners
Syukriyatun Ni'amah and
Tita Sabrina Maulinda

Link
https://robries.com/

> "We have freely adapted and deployed the Precious Plastic blueprints to our own needs. This helped us immensely to set up our manufacturing business, but we also want to give back.
>
> Tita Sabrina Maulinda

CONTEXT

Robries, a team of young entrepreneurs, is attempting to alleviate Indonesia's massive plastic problem. Robries has experimented with different processes and products, originally turning trash into 3D printing filaments produced by a modified Precious Plastic machine. Their main focus shifted to creating upcycled plastic furniture in modern minimalist designs to give single-use plastic a new and extended lifetime. After receiving private investment, production was scaled up from 20 pieces per day (one worker manufacturing one product per hour) to hundreds (one worker only needing 5 minutes for each product). Today they employ around 30 people. Demand is currently higher than production capacity so discussions are ongoing about further scaling.

Although Robries is an independent company, it can also be understood as a node in the global network of Precious Plastic projects with the open-source hardware blueprints having been adapted for local use. In this sense, it is an example of networked distributed manufacturing based on shared information between autonomous nodes.

MOTIVATION

Open source hardware: On the global level, the Precious Plastic network creates and shares open-source blueprints for machines to enable recycling plastic locally.

Sustainability: Robries is committed to recycling plastic into design products with longer life cycles, such as furniture. This is consistent with their underlying concerns with sustainability and their main goal to alleviate Indonesia's plastic pollution problem.

CUSTOMERS & REVENUE STREAMS

Local retail: products are mainly sold on the local market. Finished products, such as tables and chairs, tabletops and other decorative elements are sold to architects and interior designers, as well as cafes, restaurants, workspaces and private customers

Exports: Robries exported small batches of products via the Precious Plastic Bazaar website. Additionally, there is a Bali-based British customer who exports to the UK (who made them raise the level of attention to quality control)

Bespoke projects: e.g. in 2022 Robries collaborated with a newly opened museum to design and produce their facade out of more than 200,000 pieces of plastic waste

PARTNERS & ECOSYSTEM

Precious Plastic Community: beyond the machine design, this connects makers, entrepreneurs, and artists to share their creations and promote sustainable practices, and recently also offered marketing support.

Waste banks in Indonesia act as intermediaries between households and waste buyers and recyclers to acquire appropriate plastic. Collaboration with the local waste bank was important particularly during the pilot phase.

Local networks provide them with novel projects, such as the opportunity to design and produce the facade of a new museum

SUPPLY CHAIN

Local sourcing, linear growth: initially, Robries sourced plastic from the local waste bank, processing the material themselves (separating colors, shredding it into flakes, washing, and finishing). As they have grown, these operations have been outsourced, and Robries now buys directly from waste collectors who supply the material already color-separated, shredded in flakes and washed, instead of acquiring mixed bottle caps from the waste bank.

CHALLENGES FOR SCALING

Access to resources: while in Indonesia there are many small-scale local production sites prototyping and experimenting, most projects are not making ends meet. Manufacturing in a distributed way is acquiring recognition, however the ecosystem to support this kind of development is still lacking.

Local ecosystems for DM: while in Indonesia there are many small-scale local production sites prototyping and experimenting, most projects are not making ends meet. Manufacturing in a distributed way is acquiring recognition, however the ecosystem to support this kind of development is still lacking.

Upskilling workers: having having the team ready for scaling up was a challenge. As the system, tools and machinery were updated, staff members had to be re-trained and adapt to ongoing changes.

Emissions and personal protection: The Precious Plastic community does not respond consistently to such concerns, occasionally leading to reports of harm or lack of compliance with measures of protection. According to Robries, there are also no relevant regulations concerning environmental protection for plastic recycling in Indonesia, but they have hired a specialized company to perform a RoHS (reduction of hazardous substances) assessment on their final products.

ENABLERS FOR SCALING

Education and mentoring programs: both founders have studied, and were mentored along their evolution, which helped them professionalize, have access to resources and eventually, financial capital.

Private investor: raising investment was important not only because of access to the finance but also of having oversight and guidance from the investors.

Precious Plastic Community: both in terms of sharing open hardware blueprints, but also the existence of the community for exchange was an enabler, as such bottom-up approaches are still new in Indonesia.

SCALING OUTLOOK

Stabilizing period: Robries is currently stabilizing their production processes with their updated machine.

Scaling prospectus: The market demand still exceeds the production capacity, which means they have room to scale further. Alternatives are being discussed, which range from:

- replicating their business in other parts of Indonesia,
- creating a system of franchising, focusing on the machine and production system, or
- consulting for similar lines of business as sources of revenue.

WAZI VISION

FACTS & FIGURES

Sector
Assistive Technology & Healthcare

Founding Year
2016

Locations
Kampala, Uganda

Owners
Geogette Ndabukiye, Brenda Katwesigye and Grace Kansiime

Link
https://wazivision.com/

> “We want our eyewear to highlight the artistry and creativity of artisans across the continent. Every pair of Wazi glasses today is designed by African artisans, for African customers.
>
> Brenda & Georgette
> Cofounders, Wazi

CONTEXT

Wazi Vision is a social enterprise based in Uganda that specializes in the design, production, and distribution of affordable eyewear for children and adults. Since their establishment in 2016, they have pivoted from injection molding of generic frames to bespoke manufacturing using CNC processes. The expensive, import-driven eyewear market is made more accessible with Wazi Vision’s expansion from customized production of frames to eye care services such as ophthalmic examination for patients. They are offering products and services by partnering with local hospitals and eye care centers.

MOTIVATION

Accessibility of healthcare: More than 2 million people in Uganda need prescription eyeglasses annually but they are often expensive due to importation and lack quality.

Local production and repair: They partner with local hospitals and eye care centers to offer ophthalmic examination services to patients needing prescription glasses and enable them with locally made glasses. Users also get repair services even after years of use, increasing the lifespan of the product.

Personal customization: The frame is customized for each user, providing better comfort and durability.

CUSTOMERS & REVENUE STREAMS

Retail, including B2B and B2C: sales of bespoke eyeglasses, ophthalmic examination and eye test services.

PARTNERS & ECOSYSTEM

University-based infrastructure: the venture started from the Makerere University injection molding facility.

International support: the business scaled with support from the UKAID Assistive Tech Impact Fund and GDI Hub in 2020.

Partnerships with healthcare: partnerships with hospitals and eye care centers for products and services.

SUPPLY CHAIN

Local materials and production: local materials and CNC machines are used to produce eyeglass frames, including post-processing steps such as testing and fitting.

Demand-based production: production begins after the request from the customer is submitted, eliminating the need to invest in inventories.

CHALLENGES FOR SCALING

Production facility: during the early startup phase, access to design, prototyping and production facilities were challenging.

Technical limitations: the original experimentation with injection molding and 3D printing was limited and had to be replaced with CNC to be able to produce multiple designs faster.

Financing: it was only after years of experimentation that the venture received capital investment in production and testing facilities, making it easier to pivot.

Material and process limitation: Currently only making eyeglass frames from acetate sheet and CNC process, but there is greater demand for metal frames for which there is no capacity yet.

ENABLERS FOR SCALING

Skilled local workforce: e.g. a skilled local engineer capable of creating new designs and producing these in high quality, rapidly.

Venture building support and investment received from UKAID AT2030 Assistive Tech Impact Fund, including mentoring to move from injection molding and 3D printing to CNC.

Institutional promotion: government, hospitals and local institutions support and promote local products and services.

Networks: Supplier networks and partnerships with eye care centers have enabled scaling efforts, replacing distribution chains the venture would have had to build themselves.

SCALING OUTLOOK

While Wazi Vision was able to deliver around 1,000 eyeglasses and brought eye examinations and treatments to around 2,000 people in remote communities in Uganda last year, they now have a production capacity of 300 frames per month. They are currently opening a second store, and are onboarding new partner hospitals to scale. When such partnerships allow for expansion, they increase their work hours and further develop their solutions to maximize production capacity before purchasing more machines.

APPENDIX 2.

LITERATURE REVIEW: ADVANTAGES, CHALLENGES AND ENABLERS OF SCALING DISTRIBUTED MANUFACTURING

The main goal of the literature review was to map existing approaches and identify knowledge gaps within the literature (Snyder, 2019) regarding scaling distributed manufacturing (DM) in the Global South. What the authors found is that - probably because DM is still a novel approach, and both academic and gray literature is scarce, especially regarding scaling models. To be able to conduct the groundwork towards viable scaling models, the review focused on traditional manufacturing and was supplemented with literature on open source software and hardware, makerspaces and maker communities, the humanitarian sector, and non-industrial approaches to innovation, e.g. grassroots and social innovation.

Here, we offer a short summary: starting with key definitions, then highlighting the advantages, challenges and barriers and enablers of DM.

The complete paper outlines further considerations for the report and is available upon request.

TWO DEFINITIONS: DISTRIBUTED MANUFACTURING AND SCALING

The literature review offered a first definition of DM. According to Srai et al., DM can be defined as the outcome of "recent breakthroughs in production and infrastructure technologies that have enabled smaller (and micro scale) manufacture much closer to the end-user" (2016). Building on this, the authors found that DM represents decentralized and geographically independent distributed production, fostering connected, more meaningful and durable relationships between the producer and the end user, changing the social context of consumerism, and exploring small-scale economic models. A generally accepted definition does not exist yet, and the same can be stated about scaling, even though the term scalability is used often and liberally. In centralized models of manufacturing, scaling means the growth potential of a project or company and the ability to exploit economies of scale, with the promise of exponentially increasing returns to scale (Srai et al., 2016). However, DM does not act like conventional businesses this definition is based on. Therefore, based on the proximity of DM to the local community, its context and needs, the authors proposed using a definition created for the humanitarian sector: "Building on demonstrated successes to ensure that solutions reach their maximum potential, have the greatest possible impact, and lead to widespread change" (Elrha, 2018).

WHY DISTRIBUTED MANUFACTURING?

Most literature on and related to DM agrees that scaling is a challenge (Chituc & Restivo, 2009; Srai et al., 2016). This should not come as a surprise, taking into account that DM is often celebrated for its smallness. This means that scaling models will have to be innovative. The reasons why it might be worth investing into developing those scaling models lie in the potential advantages DM has to offer. Literature shows that especially in the Global South, but also in resource-scarce environments in the Global North (Obydenkova et al., 2018), DM could future-proof production processes and manufacturing (McDonald, 2016). Through **appropriate designs**, DM brings about opportunities for personalisation, scaling up local enterprises, and utilizing spare capacity (Srai et al,. 2016), and allows for catering to a particular area's specific requirements and resources, resulting in more effective and appropriate solutions for the local community (Oldfrey et al., 2021). **Community** is an important keyword: DM is not merely Industry 4.0 and Smart Manufacturing, but it also encompasses participation, extending to the end-user from design to production, also supporting a shift from centralized production to more context-appropriate manufacturing in the Global South (Srai et al. 2016). Maker communities are by definition part of open manufacturing and the DM paradigm with a rapidly growing ad hoc infrastructure of workshops and protocols[1] (Srai et al., 2016). Such community-based production is quite unique to DM, resulting

[1] Here, we would like to note that making and DM are not terms to be used synonymously. Making is a community-oriented practice with various tools that can be used in DM, however, DM is closer to manufacturing, and therefore, products are its main output. DM can happen in makerspaces, and maker communities can contribute with their skills to DM, thus, the two can reinforce each other, but these are two distinct concepts.

in digital platforms connecting a distributed network of makers (ibid.). Further potential social impact is the possibility to stimulate economic growth and generate **employment opportunities**, especially in low- and middle-income nations (Oldfrey et al. 2021). In this scenario, DM itself can be used as a tool for scaling local enterprises (Srai et al., 2016), resulting in advantages for local people who are, for example, engaging in creating handicrafts. Researchers have been calling for future supply chain design to manage the scarcity of resources (Malik et al. 2011; Nguyen et al. 2014, Srai et al., 2015 in Srai et al. 2016), a global problem DM is seemingly fit to address. Using local materials means **environmental benefits** and sustainable forms of production in small-scale and flexible networks, or so-called "distributed economies" (Johansson et al., 2005 in Srai et al., 2016). DM can also lower transportation expenses and carbon emissions while increasing accessibility e.g. to assistive technology in remote or underserved regions (Oldfrey et al. 2021). Hereby, it could enable greater **efficiency and resilience** by engaging local producers and the local sourcing of materials and other resources (Srai et al, 2016; Oldfrey et al. 2021). The advantage of co-creative designs being provided at a system level, and not only on an individual production node level supplemented with shared resources, such as space, machines, and expertise, leads to further advantages DM might have over traditional manufacturing.

CHALLENGES AND BARRIERS

According to academic literature, there are specific prerequisites to scaling DM, including "maturity of technology, material control, understanding of material properties, monitoring (e.g., remote monitoring), sensors, and connection to the customer base, supplier base, consumer base" (p. 18 Srai et al., 2016). If these are not enabled, scaling might not be possible. **Technology and production readiness** could be defined by the possibility of digitizing information and the manufacturer's proximity to and awareness of existing facilities (ibid). The customers and target audience need to be "ready" as well: the processes have to be transferable to other communities to scale (Dees et al., 2004). Due to the novelty of DM, there is still significant uncertainty around **viable business models** (Srai et al., 2016). Similarly, a lack of financial strategies embedded in those business models, and the lack of **access to financing** can hinder the scaling of DM. This is a sector-wide and complex issue as projects are often stuck with grants (Taylor & Salmon, 2022), which are unsustainable and risky (Dees et al., 2004). Bootstrapping, i.e. "the use of methods to meet the need for resources, without relying on long-term external finance" (Winborg and Landstrom, 2000, p. 38), has limited scalability and hampers growth (Patel et al., 2011) and scaling. Core funding is also hard to secure, so investing in organizational capacity to scale becomes very limited (Elrha, 2018). Due to the lack of adequate funding for scaling, it is seen as risky and can be expensive (ibid). While these are challenges for innovators in general, DM and its novel approaches (contextually relevant production, cooperation with the local communities to develop designs) show great potential. While DM has major potential to solve issues related to **infrastructural challenges**, the problems persist and new ventures depend heavily on the local environment to acquire resources (Stampfl et al., 2013). The shortage of digital and conceptual infrastructure, e.g. data sharing protocols or ICT connectivity can hinder scaling DM as models rely on process analytical technologies (PAT), smart packaging using printed electronics, RFID, Near Field Communication (NFC). Similarly, issues with **supply chains** and the **availability of materials** can also hinder DM, depending on whether production processes require complex material management, or are "simple" 3D printer farms which only require the right filaments. The question of materials, their control, properties and monitoring is also a prerequisite to DM (Srai et al. 2016), and represents a complex task, which needs to comply with **legislation**. The lack of fitting standards and protocols for collaborative manufacturing processes like DM can cause barriers to many projects (Srai et al., 2016), including to international scaling, as regulatory divergence results in difficulty accessing different geographical markets. Legal restrictions inhibit scalability, whereas the internationalization of business models that might be easily rolled out in different countries could be a relatively easy way to scale (Stampfl et al., 2013). **Quality management** also remains a challenge, especially in disaster situations. If manufacturing is to be maintained while assuring the quality control and the delivery of products, these are costly and complex tasks (Srai et al. 2016).

ENABLERS

Recent **technical and societal developments** have supported the development of prerequisites for maturing DM. A major uptake in the number of makerspaces worldwide, various global and community-based platforms supporting the sharing of open source blueprints, growing penetration of the internet, and subsequently the window of opportunity the COVID-19 pandemic created have shown that DM has sufficient enabling factors to scale. **Developments in production technology**, such as additive or continuous production process technologies, sensors, process analytics that can enhance production control, ICTs supporting supply chain integration, and data analytics providing insights from raw and embedded data (IoT), Enterprise Resource Planning (ERP) (Srai et al., 2016) are supporting the trend. Technology can define or enable the business, and it is up to DM strategy to decide if the technology supports the design of the processes or the processes are defined by the available technology (Elrha, 2018). There is growing interest in **sustainability and circular economy** and DM has an advantage here, e.g. closed-loop production and consumption or the re-capturing of valuable materials (Srai et al., 2016) are approaches developed through circular economy, as well as repairability and modularity leading to more sustainable practices. A distributed approach can e.g. be applied to recycling HDPE plastic (high density polyethylene) in rural areas – effectively reducing the overall cost of recycling taking into account logistics and storage in comparison to centralized recycling strategies (Kreiger, 2012). DM can also happen **closer to the end-user**, not only physically but also in the sense of design, which means a major advantage in terms of adaptation. Input from regular customers and from the front line (Tam et al., 2014) is viewed as an enabler of scaling and responsive supply that allows for the immediate pivoting of products to respond to the end-user's input. Another key to scaling close to DM's values is building the right **networks and utilizing partnerships that can** enable rapid and wide-ranging scaling. As key actors are mapped, factors shaping the actions of various stakeholders in the network can also be better understood (Taylor & Salmon, 2022) and strategically built upon. Industry-wide co-creation is also used in circular economy approaches, leading to new ideas and technologies which are built into the business model; thereby changing the industry itself and creating better conditions to scale (Hultberg & Pal, 2021). It can be argued that DM is even better suited to this approach due to its distributed nature.

FINAL THOUGHTS

DM is still at the beginning of its journey. Plenty of prerequisites are not yet present in many ecosystems, financing is scarce, bootstrapping is not sustainable, and uncertainties are prevalent around business models necessary even before scaling. There is not one linear pathway for any DM project, but iteration and rapid responses to changing social, political, economic and technological landscapes are necessary. There are high expectations and optimist narratives around resilience, sustainability, democratization and future-proofing. These potential advantages of DM over traditional manufacturing carry in themselves the promise of a better world. DM can transform systems. Above, we offered a short summary of how many different aspects of manufacturing and society could be changed by DM. Such wishes for change can lead to difficulties and dilemmas, especially as DM operates in spaces where they attend to local specificities. When scaling, they also need to aim for wide-scale diffusion. The same is true when starting out with small (project-based) solutions to change major structures of economic and political power (Smith et al., 2014). Thus, the question remains: Do DM projects remain fillers of small gaps, or can they scale and transform major systems? The promises need to be investigated and proven or disproven, to form a clear picture on whether DM projects can live up to the expectations and what is needed in terms of support to make that happen.

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