Opportunities and challenges of distributed manufacturing for humanitarian response

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***Abstract*—Distributed manufacturing, where decentralized small, local sites are engaged in production, often supported by digital systems and networks, can be a powerful tool in humanitarian aid. Field Ready uses distributed manufacturing to produce essential non-food items locally where they are needed during humanitarian responses. Such supplies can be available to communities in need and to relief workers more quickly, more cheaply than alternatives, and provide appropriate solutions to problems, often engaging local people in designing and making necessary items, and supporting economic development. Scaling up this requires local production capabilities (skills, tools, and information such as designs), which can be boosted by adoption of these methods by aid agencies, international non-governmental organizations (INGOs) and others. Local manufacturing offers the potential for disaster affected communities to be engaged in recovery, and long term to become more resilient, with access to all the equipment and information required to make the supplies they need. However, there are challenges: appropriate quality control for distributed manufacture, unlocking the potential for in-region manufacturers to engage in humanitarian response, and uptake of digital knowledge sharing and collaboration to the humanitarian sector. In this paper, we share experiences of human-centred design and global collaboration to solve local problems, of manufacturing in remote and challenging locations, community building and bridging sectors through the Humanitarian Makers network, and new ideas for distributed manufacturing standards and quality.**

Keywords—distributed manufacturing, open hardware, disaster relief, making, community, collaboration, quality control, testing, digital manufacturing

I. Background

The challenges facing humanitarian logistics are highly pronounced. These include enormously challenging contexts which lead to “sudden and unpredictable spikes in demand, difficult to access locations, disruptions due to conflict or disasters, as well as normal supply chain problems of leakage, spoilage, and other losses”[1]. This means that simple procurement orders for items like medical disposables can take weeks and sometimes months to fulfil, severely impeding humanitarian operations. Field Ready’s work addresses the challenge of logistical supply chains in remote and low-resource settings. Each year, there are several hundred declared disasters worldwide, affecting as many as 300 million people [2]. When the extent of extreme poverty is factored in, the magnitude of the challenge is very large. Countries devastated by war, natural hazards and underdevelopment are especially difficult to support and responding to these disasters is frequently slow and plagued by inefficiencies. Key elements of the supply chain – procurement, transportation, warehousing and ‘last mile’ distribution – must be undertaken in an environment of considerable uncertainty which, typically, suffers from disruption of physical and communications infrastructure.

Populations in these settings require more than basic, mass commodities. They also need individual “one-offs” such as replacement parts for crutches or eyeglasses, a fitted medical part, or spare parts for high value assets which have been damaged, such as hospital equipment, generators, or pumps. Logistics is not only central to any assistance project, it is also the most expensive. Several researchers estimate that 60-80 percent of costs related to humanitarian aid is spent on “logistics”[3]. According to Taupiac, humanitarian groups “procure an estimated US$50 billion worth of goods and services from local and international suppliers, with the procurement of goods representing around 60 percent of all procurement expenditures”[4]. When customs clearance, transportation, storage, middlemen and administration are added in, the costs of basic items are often exorbitant. The local manufacturing approach addresses those hundreds of millions of people affected by disasters each year and the roughly 45+ million currently forcibly displaced worldwide [5], plus aid workers. Ultimately, this work will include situations that are not only traditionally “humanitarian” but also undergoing reconstruction or are in extreme poverty (where development is most difficult).

Currently, the standard model of humanitarian aid involves manufacturing supplies in one location (e.g. China), storing these goods in depots (e.g. Europe) where they wait for onward shipment to areas of humanitarian concern. In Nepal, for instance, simple measuring boards used to monitor the growth of infants are shipped from Copenhagen at significant cost. This can take weeks and often months. There is no “Amazon Prime” in disaster situations (although pioneering work with last mile delivery solutions using drones shows promise for some situations [6], and modern ecommerce logistics is starting to reach new areas [7]), and that approach is not workable in highly disrupted contexts affected by war or disaster. If something gets lost, broken or the wrong item is sent (which happens frequently), the process starts over. Improving this model needs system-wide change, which the humanitarian sector is starting to recognize [1].

Further, people on-the-ground in humanitarian responses sometimes lack the training and equipment to find proper solutions, but they nonetheless try. As examples, in Haiti they have used old dirty shoelaces to tie off the umbilical cords of newborn babies, and in Syria first responders use unfiltered fuel in their vehicles - which eventually renders the vehicles inoperable. There are several downsides to these practices including a greatly diminished utility of expensive equipment, opportunities to reduce suffering are lost, and morbidity and mortality are increased.

Local manufacturing offers a range of benefits – primarily, in bypassing the slow, costly and often broken longer supply chains used in relief. It also enables existing in-region economic activity to continue, without the deleterious effects of ‘dumping’ products from elsewhere on the local market. It is likely that local manufacturing will also support lower energy and carbon consumption, reducing transportation, and may also unlock greater levels of reuse and recycling of materials. The capability and capacity to make locally will also increase local resilience to future disasters, enabling communities to be more self-sufficient if external supply chains are damaged, which is important as the risk of climate-related and other shocks grows.

II. Pioneering Local Manufacturing for Humanitarian Relief

Most innovations to date have focused on incremental improvements to the supply chain. Field Ready’s approach is different because it focuses on making supplies where they are needed, and we work with other organizations to ultimately transform the way aid is delivered.

Field Ready meets humanitarian need in some of the most difficult places on earth. Our first objective is to make – fabricate and manufacture – useful items, such as medical and water-related devices, where they are needed. We do this by working with local communities and relief workers to identify real needs on the ground, then solving problems through design and local manufacturing. We create, share and reuse designs for essential humanitarian supplies, which can be made anywhere, often using local or recycled materials, and we actually make things and help others make them, too.

Fig. 1. Field Ready model.

We facilitate skills enhancement for local people and aid workers, creating safe spaces where people can understand and tackle problems, with support, resources, tools, links to finance and potential customers, and recognition, so that they can design and make their own solutions. Finally, we develop and share these innovations, for anyone to participate. We do this by sharing designs, instructions and training materials online, and connecting people so they can collaborate.

We've shown that it's possible to use 3D printers in remote and challenging settings (as early as 2014-5 [8]), enabling local people to identify their needs and make the items they require themselves. It's not just digital manufacturing though - we also use low tech ways to make things, with understandable instructions for reliable results.

We have proven the concept using local manufacturing of supplies in the US, Haiti, Nepal, Kenya, and Syria. We have a wide range of partnerships, and are now extending our work in other humanitarian situations, field testing new manufacturing methods and sharing our designs and learning. Field Ready achieves scalable impact by pioneering new techniques and demonstrating that local production of humanitarian items is possible, and delivers appropriate supplies more quickly and more cheaply than the alternatives. We amplify our work through sharing information online, finding ways to increase local manufacturing capability and unlock the ability to address humanitarian needs at scale, and driving innovation in large aid agencies and international NGOs, to transform how they deliver aid around the world. Field Ready demonstrates that new technologies can work in the most remote and difficult areas; if it possible to use digital manufacturing to make useful items there, it can be done anywhere. But it is far more than just technology – an ecosystem is needed, which respects the complex social, cultural, economic and technical aspects of a humanitarian crisis. This is why we work so much in partnership with others, especially aid agencies and international NGOs who help us work appropriately in these settings [9].

Unlike other aid organizations that emphasize technology, Field Ready is not focussed on a single manufacturing technique, product type or location, or “a solution looking for a problem.” This means we find appropriate solutions to the problem in hand, and use fast testing and learning so that we can rapidly figure out what works, and what doesn’t. This variety enables us to learn about both the breadth and depth of different needs and contexts, so we can spot opportunities for reusing techniques and ideas, and develop rich and well-thought-out solutions that can be applied in many situations, enabling us to quickly grow our impact.

Starting in 2017, we are enabling our most useful designs to be replicated in other places, by creating “kits” which provide all the equipment and information needed for reliable local manufacture of specific key supplies or sets of supplies, and identifying business models which will enable these kits to be adopted at scale. All this makes humanitarian aid more efficient and effective, providing supplies to people in the most challenging circumstances, and empowering them with new skills to recover and rebuild.

III. Innovation in the Humanitarian Sector

We believe that the aid sector is now ready for new kinds of humanitarian supply chains. There is a new focus on innovation and a new generation of aid workers arriving in the field who are more inclined to make smart use of the latest technologies.

Also, within the last decade, 'making' has exploded from a new fad for hardware tinkerers and hobbyists to a worldwide movement of tech and social enterprise professionals. The maker movement today is represented in dozens of countries - in developed and developing countries, in urban and rural settings; in makerspaces large and small, rich and poor. Thousands of makerspaces now exist all over the world, with increasing numbers in developing countries. Their focus at the time of writing tends toward one or more of science and technology education, skills training and school outreach, entrepreneurship and the joy of making things. There is clearly scope to build on this movement and extend it to manufacture of locally useful items, not just as one-off design and build projects, but to produce standard items. We are already finding that this energy and interest can be partially directed to support humanitarian relief; for this to be effective, skilled manufacturers and makers need to be aware of the possibility, and to have open access to ways they can contribute.

An assumption is that aid agencies will be willing to change and to buy locally made supplies (or for the aid system to enable local communities to buy supplies themselves). Procurement practices often encourage local purchasing already where possible. We have already demonstrated that such supplies can be better (more appropriate), faster (or available when alternatives are not) or cheaper (lower cost when delivery is factored in) than alternatives. The next prerequisite is ensuring there are no obstacles in the procurement process which would prevent agencies from buying locally. It is also important to recognise that even in poverty, people wish to have products which are of good quality, not cut back “for the poor” – products need to be desirable and appropriately positioned. Ensuring supplies can be made reliably, and to meet relevant standards, is critical here.

IV. Results to Date

Field Ready has demonstrated the viability of local manufacturing to meet humanitarian needs in a variety of contexts. Our work has also shown that it's possible to use 3D printers in remote and challenging settings [10]. We also use other techniques, including injection molding, plastic welding, soldering, sewing, laser cutting, and plastic recycling and reuse systems. We have made simple medical items (such as umbilical cord clamps originally designed together with midwives in a Haitian clinic, and tweezers) using 3D printing (3DP)[11], and designs from shared online “instructables” often using recycled or reused items (such as rat traps made in a refugee camp from plastic bottles). The following case studies highlight specific aspects of distributed manufacturing for humanitarian relief.

A. Human-centric design of humanitarian relief items

By working with sector experts and relief workers, we can integrate human-centric design into useful items. Our work in the field always starts with assessment, to understand the context and needs, before moving on to problem solving where appropriate.

Many aid agencies in Nepal are working to supply equipment to remote health posts, who lost a lot of their supplies in the earthquake. Procurement processes to do this could take over 4 months, so Field Ready started a project to develop 3D designs for basic medical items so they can be 3D printed in the field. Whilst redesigning the items for 3D printing, we had the chance to work with local medical practitioners to get their input into the design process. One of our favourite devices that came out of this is a non-surgical kidney tray. These are usually made out of plastic or metal, are used to hold small implements up to a patient’s face, with a smooth inner radius to enable health professionals to scoop implements out of the tray easily when needed.

Through the design process, we learnt that plastic kidney trays are much preferred because they are lighter and easier to hold in uncomfortable positions, and that medical staff dislike that the wide smooth radius makes the trays unstable and easy to knock over when sat down. Through design, we were able to maintain the smooth inner curvature whilst giving the tray a wide flat base, and to manufacture new trays locally with 3DP. The digital design is now available online, and can be produced by anyone, anywhere in the world where kidney trays of this type are needed [12].

B. Repairing high value assets: one-off replacement parts

In Nepal and elsewhere, we have 3D printed replacement parts for equipment, which is important in developing countries where items, such as medical equipment, are often second-hand donations. When they break, it is hard or impossible to get new components, as the equipment is often obsolete and parts are no longer available anywhere. For example, we made new corners for hospital baby warmers in Nepal, where the corners had broken leaving dangerous edges so that the warmers could not be used. Our new corners are stronger than the old ones which kept breaking, and all the baby warmers are now back in use [13]. Such work has disproportionate and hard to assess economic value – the plastic part itself is cheap to make, but the benefit of having functional complex equipment in operation from the time of repair is significant.

C. Enabling life-saving equipment in inaccessible areas: search and rescue airbags for Syria

As part of the Syria response, we have designed a lifting airbag for use in search and rescue, which can be made where needed (including besieged areas) using local materials and hand tools, which is a fraction of the cost of commercial alternatives [14]. The airbags made locally have been used to rescue a number of people in Syria and pass tests equivalent to the relevant British Standards [15]. This is an example where simple manufacturing techniques can be conveyed purely through instructions, allowing reach into areas where products and new tools are entirely unobtainable. The cost reduction compared to commercial airbags is also significant, and suggests opportunities for larger scale adoption.

D. 3D printing for faster, shorter supply chains for relief items: cookstoves

A large international NGO involved in the Nepal earthquake response - World Vision Nepal - ordered 423 efficient solid fuel cooking stoves of a type pioneered in

Africa. Upon delivery from the manufacturers in South Africa, some of the control knobs were damaged and would need replacing. Procurement of the stoves themselves had taken months.

Moniek at World Vision had worked with Field Ready before, and she was on a very tight turnaround to get spare knobs to send out on the distribution to quake affected areas. 3D printing the parts in Kathmandu was much quicker and cheaper than procuring spares from the original supplier, who could not get the parts to her in time. She met Field Ready's local team, and we explored the problem with the cookstoves. We used 3D printing to make 423 of them, which we sold for 55 rupees each [16]. The cookstoves were distributed and are in use on 10 sites. The knob design can now be reused to fix cookstoves of this type anywhere in the world, and we have shared this improvement with the original manufacturer. Field Ready coordinated with World Vision to deliver the products in phases ahead of delivery to their final destinations, by making extensive use of local production capacity, so that were similar or even larger orders of this kind of item to be received today, they could be fulfilled using dispersed manufacturing throughout a network of 3D printers and local makers that Field Ready has been instrumental in supporting and developing.

E. 3D printing: the power of customisable digital design

With a university partner, we have created an app which takes pipe size measurements and automatically generates designs for 3D print custom pipe fittings to connect water pipes. This means that a custom water pipe connector can be made which works for whatever size pipes are available. We have tested this design in the water supply of a camp for displaced people after an earthquake damaged their homes and are now exploring the further potential of this sort of customisation [17]. Digital design and manufacture tools like this can move the ability to customise items to people at the edges, who may not have traditional design skills.

F. 3D printing in remote environments

3D printing is a powerful technology – along with other digital manufacturing techniques, both additive and subtractive – which enables one machine to make a variety of items in a highly repeatable way. 3D printers are quite variable in quality, robustness and reliability, and we have extensive experience in what features to look for in selecting field printers. Commonly, we are asked about power and materials. We have shown that 3D printing is possible powered by remote and renewable sources, including solar[18] and vehicles[19]. Whilst it is often necessary to bring in the raw material filament for printing, this still offers advantages over shipping specific items (which may not be what is most needed on the ground), and techniques for recycling filament and making it locally from waste plastic show promise (although these may not be suitable for some medical/surgical items).

V. NETWORK EFFECTS: INFORMATION AND COORDINATION AROUND LOCAL MANUFACTURING

Together with partners, we have identified a need for online infrastructure for information sharing relating to local manufacturing and production coordination across humanitarian and development actors. This community includes international NGOs and UN bodies, local NGOs and communities, engineering and maker communities around the world, and manufacturers, and spans production spaces which are in urban, rural, and improvised settings.

This infrastructure will unlock the potential for local production of supplies. It will include systems to enable open sharing of information about how to make useful items (design files and instructions), how to repair high value assets, and ways to find skilled assistance, materials and equipment; it will also extend to enabling distributed manufacturing to meet humanitarian and development needs by offering easier channels for suppliers and purchasers. This will enable better, cheaper and faster delivery of essential items in all kinds of crisis situations, from rapid onset disasters to long standing refugee camps. Such information is either not available today, or is scattered, or is in unusable forms. We seek to gather these different kinds of information, and collaboratively build the software, standards and networks to enable relief workers, humanitarian and development agencies, social enterprises and local manufacturers and makers (including in affected communities) to find, share and use it effectively to support the production of supplies when and where they are needed.

We are using lean and agile software development practices to explore and validate ideas with potential customers and stakeholders, and to build a consortium of organisations who can support both initial development, and ongoing maintenance. This consortium will act as the home of the diverse organizations interested in this area, and any necessary standards. The activity currently has two major strands, on design sharing and collaboration around individual products, and on coordination of distributed manufacturing.

A. "Makepedia" design sharing and collaboration platform

"Makepedia" will be a platform for sharing designs for humanitarian, reconstruction and development supply items, providing a basis for collaboration and open knowledge sharing around how problem solving and manufacturing in remote and crisis settings. We are now taking forward a proof of concept towards a minimum viable product (MVP), populated with content and in use by a diverse "supply side" community (meaning those who are, or could be, engaged in supplying humanitarian essentials, including designers, engineers, and in-country manufacturers).

As an online catalog of free and openly shared reliable and safe designs for essential humanitarian supplies, Makepedia will enable local people and aid workers to instantly download and manufacture quality tested and effective items and spare parts, often using local/recycled materials, and with full instructions (often pictorial). We have evaluated available platforms against our existing requirements based on extensive field experience from Field Ready and partners, and know that a sustainable and globally acceptable platform solution does not yet exist, so we must create it, building on or influencing existing systems as far as possible. Open source components can easily be reused; where only closed source is available we are already engaged with some platform providers to discuss changes which would enable reuse. Based on our work to date, Makepedia needs functionality which goes beyond today's predominantly commercial, proprietary platforms.

For instance, on Makepedia, anyone should be able to share designs, but some organisations should be able to 'certify' or mark some designs as reliably manufacturable, producing safe items with good documentation around risks and safety in use. Ideally the platform will support "forking" of designs or manufacturing instructions (for use in different contexts, such as climatic conditions), ease of translation of documentation, and the ability to review changes and collaborate on design and documentation improvements. Download of design information packages is also important for use in remote areas with poor connectivity.

B. *"Makernet" – coordination of distributed manufacturing*

At large scale, local manufacturing for humanitarian relief demands business models to be in place which resource production and delivery of items to those in need. Whatever the financial structures around humanitarian relief, reconstruction and development, information about suppliers and purchasers of products needs to be available to the right people at the right time.

We have a vision of numerous small-scale manufacturing enterprises, connected to markets in their communities and regions, benefitting from the ideas of the fourth industrial revolution, and the circular economy, producing items needed in their communities from materials available locally, and are creating sustainable businesses by doing this. The manufacturing infrastructure that already exists in so many parts of the world – the informal sector welding shops, the backyard carpenters, the handy-men and women who can fix any mechanical problem - would be fully integrated into this supply ecosystem. It is supplemented by new additive manufacturing techniques, smaller-scale and greener methods of production, new types of knowledge and skills, and novel ways to prove quality. Analogue and digital manufacturing technologies would combine to enable new methods of sharing knowledge, earning money, and checking quality.

Connecting these local manufacturers with market demand, from aid agencies, INGOs and local NGOs, and channels to local markets, will enable a new model of relief and development provision. Field Ready has undertaken some early stage prototyping in Nepal, looking at 3DP capacity and capabilities around local entrepreneurship [20]. "MakerNet" is an international initiative to unlock this potential, by developing standards and systems and tools which connect makers, markets, manufacturers and humanitarian and development needs, built around ideas of shared, open source product designs. Since 2016 a consortium of organizations with diverse expertise and global reach have been exploring this area, uncovering both the 'micro' needs of makers in different countries and contexts, and the 'macro' opportunities and challenges facing making and localized production as drivers of 21st century job creation and economic growth [21].

C. *Building a movement around distributed local manufacturing for development and humanitarian purposes*

We presently anticipate that these two strands of work will lead to the development of shared open source platforms, comprising both the software and the data contained. Such a common, shared platform would benefit the agencies and NGOs and other community groups engaged in development and humanitarianism, enabling their work to be more effective. However, it is possible that a more decentralised and federated approach, using open standards around information structures and a diverse set of software platforms, may prove more appropriate.

Both concepts are being designed from the outset for sustainability, by gathering needs and requirements from multiple relevant communities. By building partnerships from the start we avoid a "not invented here" mentality and also create shared interest and buy-in which will help the project sustain. Our goal is that long term a consortium of interested organisations could contribute regular subscriptions to maintain, operate and update the platform, and to continue essential support such as community management around this, but other revenue models are possible and under exploration.

Our current partners in this work are Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), Cisco Foundation, Gearbox in Kenya, Costruct in Myanmar, Kumasi Hive in Ghana, CIVIC, IBM, plus network partners Fab Foundation and Global Innovation Gathering. We are actively seeking additional partners and have had discussions with other groups interested in this area both online and face to face. This consortium will grow and develop in parallel with the software platform and the data contained within over the coming year (of MVP development) and beyond (into full operations). Adoption may be a slow process as the aid sector is not a rapid adopter of new digital technologies but the close alignment with practical on the ground relief work from Field Ready and other partners will drive awareness and evidence generation to support take up.

VI. NETWORK EFFECTS: HUMANITARIAN MAKERS COMMUNITY

We have nurtured a grassroots community, known as Humanitarian Makers [22]. Its vision is to realize a networked community actively enhancing hardware solutions to persistent and pressing human needs. Its membership attracts humanitarian professionals as well as "makers" (designers, engineers, technicians), who remotely assist with expert-led product development needs in the field and/or are engaged in humanitarian making in their community. Humanitarian Makers can support both 'real time' and asynchronous activities, long projects and short tasks, as well as advance each other's work through information sharing on Humanitarian Makers' internet channels. We are currently exploring how in-field humanitarian prototype testing and evaluation can be enhanced by the cognitive surplus the Humanitarian Makers community represents. This is primarily testing whether designs and documentation are adequate for someone who has not been involved in the design creation to reproduce an item elsewhere.

Humanitarian Makers has an online presence on a variety of platforms and several local groups have hosted face to face meetups. The community is currently building an infrastructural team (advisors, coordinators) to help sustain itself, and continues to evaluate and explore the use of different platforms, activities and onboarding to help it be an effective tool to support humanitarian making, as well as a welcoming and inclusive global community.

VII. Building out distributed local manufacturing capabilities

Field Ready is now making our local manufacturing capabilities easier to replicate, so that more people can have access to the equipment they need to make useful items [23]. We're exploring a range of models by which manufacturing equipment (supported by instructions, training and support as needed) can be provided to more people and organisations. We call this equipment a "kit", each addressing a specific need or set of needs in the field, with potentially different distribution and funding models for each [24]. We are currently developing kits for several purposes: 3D printed medical items for clinics and health posts, search and rescue airbags, custom pipe fittings and other plastic water and sanitation items. Our goal is to increase the adoption of kits, and we are open to a range of models by which both capital and ongoing revenue may be secured. We see potential for local micro-franchising opportunities, aid and livelihood delivery partnerships, and other social enterprise models, all of which could support building local manufacturing capabilities through kits in various ways.

Through 2017, we are developing and testing our first kit, for 3D printing of simple disposable items for small clinics, enhancing equipment and instructions, and continue with user testing and engineering testing (in Nepal and elsewhere). In parallel we are refining and improving our lifting airbag design, advancing our work on water and sanitation (WASH) items, and undertaking small trials of early kits with different support systems and revenue models. During 2018 we will develop more item designs for the clinic and WASH kits, quality check and refine the kits, and run larger scale trials of further kit types with partners in multiple countries. By 2019 we will have at least two standardised kits adopted by partners in different countries and contexts.

The Field Ready team are implementing the kits concept, and welcome additional partners who can support field trials in new locations and contexts. Such trials will help refine and standardise the technology and user experience, as well as validating adoption models which can then be rolled out at larger scale.

Kits are likely to be used, in general, by people with less expertise in manufacturing than many of our current field engineers. They need to be useful and useable for such people, with or without specific training programs. Our experience shows that even with reasonable training and access to troubleshooting guides, people can encounter manufacturing problems and challenges in, say, 3D printing, which are hard to resolve. So we are testing models where, for instance, local or in-region specialist technical support services are available in parallel to help kits users. Remote support is also a possibility although not appropriate for all settings.

VIII. Key technical challenge: appropriateness

The decision to make humanitarian supplies at point of need is based upon an assessment of the situation, including what supplies are currently available and what needs are most critical.

In each context, a locally manufactured item, such as a 3D printed medical disposable item, may be an improvement over what is locally available, or roughly equivalent in quality, or it may in fact not be as good as available alternatives. This will depend on the market availability of items, plus affordability and accessibility to affected populations. The ability to judge the appropriateness of a given solution item depends on both some domain knowledge, and knowhow about how the design and manufacturing technique affect the suitability and risk profile of an item. For example, a doctor will know which medical implements are used during surgery, and a biomedical engineer will know what materials would be appropriate for use in the body.

An item made in a local context using digital manufacturing, or from recycled or reused components, may not have the properties of a commercial product version. Setting expectations appropriately therefore is important, for those making and those using such items. Just because a design can be downloaded and made does not mean it is an appropriate choice for all contexts. As well as appropriateness to solve a problem, and quality of the item, in some settings the economic value should be considered (especially if alternative solutions may be available and accessible to beneficiary communities), as well as the cultural appropriateness of a product.

IX. Key engineering challenge: Distributed quality assurance and standards

When making humanitarian supplies, there is a need for manufacturing to be reliable (a high rate of manufacturing failures is a waste of materials and labor, and could delay the delivery of relief items), and for the items produced to be appropriately safe and reliable too.

The level of quality assurance differs between innovative prototypes for limited testing, and larger scale creation of supplies in a more 'mission critical' setting. The level of risk inherent in the product and the context of its use is also critical; for example, if the product is used in life-saving settings, or if the product may affect a large population (for instance, a water pipe to a community), then the risks of different kinds of failures may be significant. As we start to see greater use of distributed manufacturing and local making of humanitarian items, these issues become more important.

Manufacturing in remote and low resource environments presents new challenges for quality assurance. The people making items may not be as qualified or experienced as those in other contexts. Test equipment may not be available as it would be in a factory setting. Furthermore, whereas in a high volume production line it can be expected that specialist and specific test equipment at different stages of production and at the end is available, using flexible techniques such as 3D printing means that a range of items may be made – both a benefit in humanitarian settings, and a challenge to test and validate!

We are also interested in what formal standards are required in what humanitarian situations. This has international variation of course, and is particularly of interest when supplies made locally may be bought by INGOs or large agencies, whose procurement systems require formally certified products today. The question of how to meet formal standards for products made "in the field" is an interesting one, and a parallel activity is working with aid agencies to explore exactly what certifications are needed, and why, and to seek appropriate solutions to this together.

To date, consideration of quality control and safety and reliability of digital manufacturing designs shared online for production on consumer grade 3D printers by people without formal qualification has been minimal or non-existent. As these techniques start to be used to make necessary items at larger scale, these issues become important.

We propose several methods to address these needs and would welcome discourse in the sector around development of these, and other, ideas.

A. Documentation, test plans and "open testing"

To deliver reliable manufacturing of items, the documentation in support of actual design files needs to be good enough to enable someone who was not involved in the design process to reproduce the item. This can be tested by getting a range of people in different locations to attempt to make the item and report their results; this is also useful in testing the reproducibility of the item and process on different production machines such as 3D printers (whether that is different machines of the same model, which may have idiosyncrasies, or different models). Testing relating to different local conditions (humidity, dust, atmospheric pressure) and local material variability is also useful.

To go beyond reproducibility, we can look at destructive and non-destructive testing of made items to evaluate their suitability for use. In some cases, testing of items made using a process in advance might be sufficient to validate that they are fit for use; for instance, for a simple design where reproducibility is high. In others, it might be useful to test the first items made in a new location, to check local materials, understanding of instructions, and machinery or equipment give acceptable results. For some safety-critical items, non-destructive inspection of every item made might be appropriate.

To have high confidence in the reproducibility and reliability of a manufacturing process and design in multiple contexts, testing could be carried out by people in many different settings, with the results reported back and collated. We call this 'open testing', and propose the collaborative development of openly-shared test plans with the involvement of engineers and sector specialists, and the open sharing of test results, would be a valuable extension to the 'open hardware' movement.

B. Design for field manufacture and field test

When designing items that will be made in distributed, digital ways in low resource environments, consideration can be given to how the maker or user can check they have a good item. This might mean adding features that make it easier to see whether a 3D print has been successful, or whether all stages of manufacture or assembly have been completed, perhaps through adding physical features which need to interlock for assembly and will only do so if all parts are present and made at a suitable print resolution. Whilst this adds to design time, and would not be appropriate when designing in the field for urgent needs, it is a good example of where remote design support can help create reliable humanitarian items asynchronously.

We can envisage field teams designing items to meet immediate needs, sharing the specifications online, and then remote humanitarian engineers and makers reworking the designs for reliability and adding 'design for test' features.

C. Process and material validation

Some aspects which could change the resulting item quality can be tested in laboratory conditions, or in other locations away from the field. For example, evaluating whether a medical item which has been 3D printed according to a documented process creates a sterile print straight away (or whether additional sterilization steps may be needed). Aspects of food safety (for items used in food preparation or storage, or water storage) might also be useful to prove out in the case of field manufacturing.

Raw materials can also be variable even if they seem superficially the same. 3D printer filament may be of high or low quality, and specific brands or grades are not always available. Types of plastic sheeting or other components used in builds may have different names or descriptions in different locations. Testing with a range of options, and building up a shared sense of what are acceptable substitutes could be valuable. We have begun prototyping some test systems which can be reproduced in other places, such as a low tech tensile strength assessment tool [25]. It is not feasible to create a global materials catalog or database, which would likely never be complete, but information about some materials can form the basis of tests which could be run locally to identify or qualify available materials.

D. New inspection and test techniques and technologies

Whilst low resource environments do not offer the test and inspection options of a developed world factory, new technologies show high potential for field testing. For instance, computer vision continues to improve, even when using commodity hardware such as the cameras available in smartphones. This could potentially be combined with lens enhancements or phone add-on modules, plus online or offline processing and perhaps machine learning, to offer smart inspection systems for field use.

E. New forms of certification

Digital design sharing offers the opportunity for designs to be marked as "verified" or approved in new ways. Different organizations might be able to test and validate specific designs for criteria which they are specialists in. For instance, an INGO might certify that a design, if made according to the instructions, meets its needs for hygiene and other factors. Field Ready might certify a design as being readily and reliably 3D printed in a field environment. Such certifications could be presented alongside designs in an online platform. Working out how to manage certifications for designs which may have variants or iterations will be a necessary component of this.

X. Next Steps

Field Ready would welcome wider discussion on these important topics in the humanitarian, development and engineering sectors, and is working to convene and stimulate conversations. A broader interest group or consortium, including engineering and standards expertise, which could work together to create shared, open solutions and methods would be a positive outcome.

There are ongoing challenges in resourcing research and development (R&D) in humanitarian contexts, and in overcoming the "silos" of many existing humanitarian supply chains, where supply chain innovation can be very disconnected from product innovation. Cross sector discourse is essential to unlock the potential for systems change and to enable new resourcing models supporting both innovation and new operational practices.

We are also seeking corporate and industry partners who can support and assist our work and provide in-kind support such as access to standards and test labs, so that we can appropriately and formally validate our product designs and manufacturing processes. R&D partnerships with academia and industry would be especially welcome. Field Ready is currently a thought leader and recognised innovator around local manufacturing for humanitarian purposes, and we want to extend that in the coming months and years to catalyse sector discussion and learning about quality levels and safety standards for supplies used in relief work and crisis situations.

Longer term, we plan further work on shared practice for quality control for more complex and higher risk items, enabling these to be made in confidence in more locations.

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