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Journal of Humanitarian Engineering (JHE)

The Journal of Humanitarian Engineering (JHE) is an open access publication that publishes outcomes of research and field experiences at the intersection of technology and community development. The field of "humanitarian engineering" describes the application of engineering and technology for the benefit of disadvantaged communities. The field spans thematic areas from water to energy to infrastructure; and applications from disability access to poverty alleviation. The JHE aims to highlight the importance of humanitarian engineering projects and to inspire engineering solutions to solve the world's most pertinent challenges.

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Cover photos:
All images are courtesy of Gilliam et al (this issue). Top - Affordable green houses utilised by women's cooperatives in South Mozambique; greenhouses increase the yield production of crops throughout the year allowing for increased financial stability for local farmers; Middle - Farmer Daniel Mucachua showing his tomato harvest; Bottom - Farmer Daniel Mucachua's seedlings growing in thermocol crates in a greenhouse in Southern Mozambique.

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EDITORIAL

The papers in this issue all demonstrate out of the box thinking, and are not the traditional forms of studies that many of us with engineering backgrounds are used to. I find this hugely exciting, as

> Journal of Humanitarian Engineering was initiated to widely share innovative thinking, particularly through free publication and access, and prompt the important conversations which may not arise from traditional journal publications.

For example, many of us have seen news images of people impacted by conflict or natural disasters fleeing their homes. There are global political debates about where these individuals and families can seek refuge in the longer term. But little is discussed in the mainstream media about the quality of their lives when they arrive in an intermediate country or region. I work in the field of water and sanitation, so I often think about whether there is adequate access to clean drinking water and safe toilets in “short-term” (we know that many families raise multiple generations here, so in some cases this is a misnomer) shelters and camps. But I have to admit that until I read Greene and Chao’s paper, I had never considered the implications of poor sleep quality, particularly on a population potentially experiencing so many other physical, mental and emotional traumas and threats. Read their paper to understand more about how improving flooring structures in temporary shelters can lead to a measurable increase in well-being.

Eseonu and Cortes’ paper highlights something that is often not at the front of students’ minds when they hear the term “humanitarian engineering” – that it is globally applicable. This should be recognised more widely than it currently is, particularly as the Sustainable Development Goals must be achieved universally, not just in countries considered to be “developing”. The paper presents an approach where university students and communities of the Pacific Northwest worked together on product, workforce and economic development. This “differs from existing project or trip based approaches – outreach – because the focus is on local communities with which the university team forms a long term partnership through weekly in-person meetings and community driven problem statements – engagement”. Such a participatory approach empowers everyone involved to bring their own skills to the table.

The final two papers by Gilliam and Mehta are the culmination of many years of research and practical work on engineering projects in low resource contexts. They discuss the myriad of failures they have witnessed over the years throughout the design, implementation and maturity phases of agricultural technologies ventures, and how the majority of these have not been due to technical issues. Gilliam and Mehta then present a taxonomy of the modes of such failures, with suggestions of how they can be addressed before projects begin, a “pre-mortem” of sorts. As engineers it is common for us to discuss failures within our own institutions or over a beer, but often as a sector we do not formally recognise and learn from them. I commend the authors on proposing a way in which agricultural engineering researchers and practitioners can self-reflect on past failures so as to prevent future ones.

I hope you enjoy reading these papers as much as I did, and that they spark some new discussions within your group of friends and colleagues.

Dr. Dani Barrington

Editor-in-Chief, Journal of Humanitarian Engineering

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CONTENTS

Engineering for Good: A Case of Community Driven Engineering Innovation

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ABSTRACT: *There is a culture of disengagement from social consideration in engineering disciplines. This means that first year engineering students, who arrive planning to change the world through engineering, lose this passion as they progress through the engineering curriculum. The community driven technology innovation and investment program described in this paper is an attempt to reverse this trend by fusing community engagement with the normal engineering design process. This approach differs from existing project or trip based approaches – outreach – because the focus is on local communities with which the university team forms a long-term partnership through weekly in-person meetings and community driven problem statements – engagement.*

KEYWORDS: *New product development, Economic development, community engagement*

1 PROBLEM STATEMENT

There is a culture of disengagement from social consideration in engineering disciplines (Cech, 2014). Engineering students arrive excited to make social impact, but lose this drive by graduation. This is concerning as the Organisation for Economic Cooperation and Development (OECD) lists science, technology, and innovation as keys for sustained economic development (OECD, 2000). Humanitarian Engineering largely focuses on clean water supply (Gordon et al., 2017), health and safety supplies or devices (Maxted, 2013), or renewable energy technology (Schultz, 2013) in low-resource foreign locations. This "outreach" approach relies on external experts to educate and provide solutions (Lochner, 2012). However, after a century of engineering outreach, "more people have access to mobile phones than to clean water" (Niemeier et al., 2014).

This case study applies a "community engagement" approach as part of as Community Driven Technology Innovation and Investment (CDTII) program. Engagement describes "reciprocal, collaborative relationships" in which community members are active members of the project team (Barker, 2011).

2 METHODOLOGY

The case study is organised into three phases – Engagement, Innovation, and Workforce and Economic Development. Phase 1, - Engagement, includes activities to develop community partnerships. Phase 2, Innovation, includes activities to create new technological solutions in response to community-based opportunities identified in Phase 1. Phase 3 - Workforce and Economic Development, includes activities to ensure the community can sustain economic and technological changes from Phase 2.

2.1 Phase 1 – Engagement

This phase focused on Community Driven ideas and trust building. The engineering team partnered with university-based colleagues in Rural Agriculture, Rural Economics, and the Centre for Latino/a Studies and Engagement (CL@SE) to organise a session at the 2013 Regards2Rural (R2R) conference. The R2R conference is a biennial event in which over 400 community representatives meet to exchange ideas, gain experience and receive assistance, and learn from practice or research findings. Community representatives at R2R conferences are elected or appointed local government, or county,

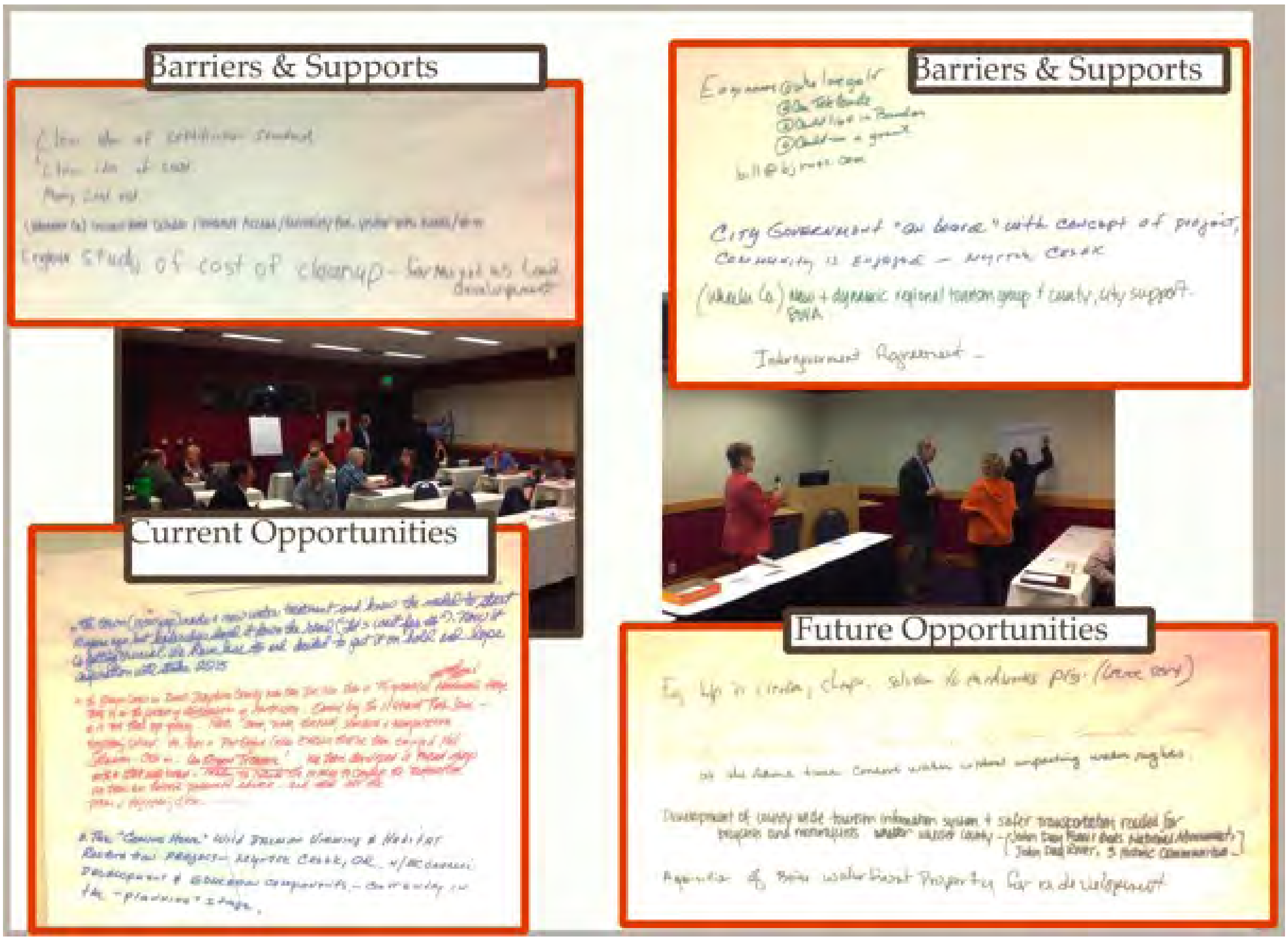

Figure 1: Brainstorm session with community representatives at Regards2Rural Conference

officials from the Pacific Northwest – Oregon, Washington, Idaho and Montana.

The R2R session objective was to explore community interest in an engineering focused approach to long-term economic development that would be driven by start-up companies. These start-ups would be formed around a technology created in response to a community need. The university team offered an investment of USD $25,000 in engineering and rural economist resourcing time for the project selected in response to the request for community proposals. This investment was made to build trust and was a down payment on a future request for communities to also invest in the potential company. Asset-based community development suggests community ownership enriches outcomes by converting community strengths (assets) into tangible inputs for development (Ennis and West, 2010).

Six projects were proposed during a brainstorm session shown in Figure 1. The team worked with community representatives at the R2R conference to evaluate projects for feasibility and technological relevance. As an example, a project that required an ecological solution for salmon management was rejected in favour of one that required a device to improve a specific production or waste management process.

2.2 Phase 2 – Innovation (Product Development)

This phase focused on the traditional engineering design process. Final year mechanical, industrial and manufacturing engineering students undergo a six-month capstone project that allows them apply their knowledge in a practical setting. More importantly, these projects expose students to project ambiguities, stakeholder demands, and unintended consequences of seemingly innocuous project decisions. Capstone projects traditionally have industrial clients who specify outcomes and can provide engineering guidance. Given the level of disengagement from social consideration. Cech (2014) describes, the CDTII team used this capstone process to engage engineering students and demonstrate practical social impacts of their engineering skills.

The projects were operated under the principle of "shared suffering," which is used to build mutual respect in virtual teams by alternating meeting times so that no single different time zone is consistently disadvantaged

Figure 2a (top left): Step 1 - Hand mix masa; Figure 2b (top right): Step 2 - Roll masa into ball; Figure 2c (middle left): Step 3 - Shape masa; Figure 2d (middle right): Step 4 - Cook sopes; Figure 2e (bottom left): Step 5 - Shape sopes into bowl; Figure 2f (bottom right): Step 6 - Garnish and serve

(Malhotra et al., 2007). In these projects, "shared suffering" is an opportunity to increase mutual learning by alternating design-meeting locations between community and university sites.

Finally, the community members are seen as active participants in the design process. This includes brainstorming, testing, and discussions about material selection. The benefit of this approach is, in part, that the engineering students solidify their learning through explanation, questioning, and re-examination of their assumptions. Research suggests that discussions, peer teaching and collaborative learning improve self-efficacy and student performance (Stump et al., 2011, Smith et al., 2011).

2.3 Phase 3 – Workforce and Economic Development

Unlike the first two phases, which focus on input actions to be taken by humanitarian engineers and community partners, Phase 3 is focused on results or long-term outcomes. Phase 3 outcomes are threefold: near, mid-to-long, and long-term outcomes. Near term outcomes include the device produced, company formed, and initial increase in employment, local income, and interest in engineering disciplines. Mid-to-long term outcomes include local and state government goals, such as work readiness and revenue initiatives like the "40-40-20 goal" in Oregon. The Oregon state "40-40-20 goal" states that by 2025, 40% of Oregon residents will have a baccalaureate degree, 40% to have an associate's degree or skills certificate, and the remaining 20% to have a high school diploma. Finally, long term success will be assessed using demographic and socio economic measures of rural versus urban trends as tests of the OECD assertion that science, technology, and related innovation are key to sustained economic development (OECD, 2000).

3 CASE STUDY

3.1 Project 1 – The Sope Maker

Three women from Monroe Oregon sought to augment family income by selling sopes – a Latin American food item – through the local Co-op. They faced three challenges: a labour intensive preparation process, inability to scale up the process, lack of standardisation in shape, quality, and content of the sopes. The current preparation process is outlined below:

Step 1: Mix the masa (dough). In this step, the ladies taught the Oregon State University (OSU) team how to hand mix the masa in a bowl to reach the desired consistency (Figure 2a).

Step 2: Roll small chunks of masa into ball shapes and set aside (Figure 2b)

Step 3: Flatten into heart shapes on a biscuit or cookie tray (Figure 2c)

Step 4: Cook on stovetop, flipping over until moderately cooked (Figure 2d)

Step 5: Remove from pan and shape edges to form a bowl – dip fingers in cool water as needed (Figure 2e)

Step 6: Place condiments and serve (Figure 2f)

This process yielded approximately 20 sopes per hour and it was identified that Step 5 posed a safety hazard as most people burnt fingers while shaping the hot sope. The engineering challenge was to create a device that would reduce labour intensiveness, produce standardised sopes at a constant rate, double the production rate, and comfortably accommodate a single operator (i.e. any device must be within reasonable lifting requirements for a single individual).

3.2 The Engineering Design Process

Phase 1: Define problem

The team answered the questions in Table 1 with minor modifications to traditional engineering design processes.

Table 1: Problem identification questions in traditional capstone versus CDTII projects

Question	Traditional Capstone Projects	CDTII Projects
Who is the customer/partner?	Partner/customer is usually an engineering company that understands engineering terms, and design constraints.	Partners were often a series of community stakeholders beyond the direct recipients of the device being created
What are the partner's needs?	Partners arrive with needs specified in engineering terminology. Problem is often a component of larger engineering project.	Partners specify business or usability goals, which the teams must convert to engineering specifications. The teams are presented with entire engineering project – no senior engineers as fail-safe.
Who is impacted by the needs and possible solutions?	Clear stakeholder delineation. Often insulated from indirect stakeholder needs.	Unclear stakeholder delineation. Direct contact with all stakeholders (e.g. city council discussions for test kitchen use, impact on families and children)
What is the nature of impact?	Normally assessed in financial and technical terms.	Assessed in socio-economic, cultural, financial, and technical terms
What are the technical aspects of the problem?	Identified with guidance from more experienced engineers.	No external/customer based engineers

Table 2: Design constraint definition questions in traditional capstone versus CDTII projects

Question	**Traditional Capstone Projects**	**CDTII Projects**
How do partner preferences influence design decisions (what conflicts exist)?	Often pre-identified and re-solved. Conflicts often financial and technical	Amorphous list of stakeholders. Unclear, multifaceted conflicts. Students work with professors and community liaison to convert preferences into engineering requirements and back into clear, non-engineering trade-offs.
Does partner appreciate how conflicts affect design decisions?	Understood without student involvement	Partners are adept at dealing with trade-offs and considering social, economic, and other implications. However, most partners are not engineers. Students must describe the physical laws that affect trade-offs between desired attributes (e.g. safe to touch) and material selection, given weight and size requirements.
Will a numeric scale for criteria importance help defuse potential tensions before brainstorming and evaluation?	Often, yes.	Works well if partners are involved in criteria development.

Phase 2: Identify constraints

The goal is to identify financial, technical, and other limitations, and assess these limitations by answering questions like those in Table 2.

Phase 3: Brainstorm alternative solutions

Traditional capstone teams often brainstorm independent of the client/partner. In this case, the community partners were involved in the brainstorming process. This was part of the engagement strategy to ensure that the community partners and the OSU team viewed each other as co-equal team members.

Phase 4: Evaluate and select viable alternatives

As with traditional project teams, the focus in this phase was ranking the alternatives generated in Phase 3 on the numeric scale generated in Phase 2.

Phase 5: Develop and test design prototypes

In this phase, the team developed prototypes and assessed results based on predetermined criteria and real time assessment by community partners. This phase, shown in Figure 3, was similar to the traditional engineering capstone experience, as the community and OSU team members had developed shared understanding of the evaluation criteria.

Phase 6: Select and implement final design

This phase was also conducted in similar fashion to the traditional capstone process. The team made modifications based on feedback from test production runs. The final sope maker (Figure 4) was introduced at an outreach and engagement symposium at the Oregon State University campus. It is important to note that the sole change to the process was made to the cooking rate. This change was in

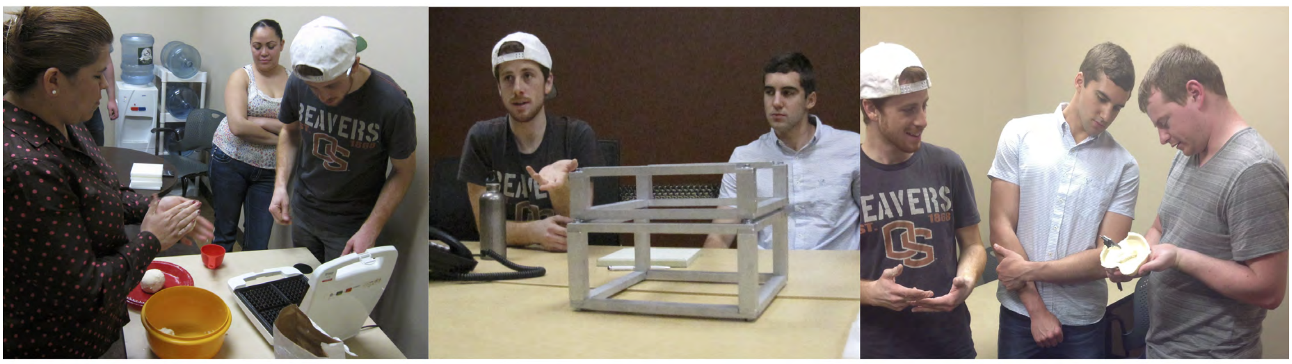

Figure 3: Prototype development and testing

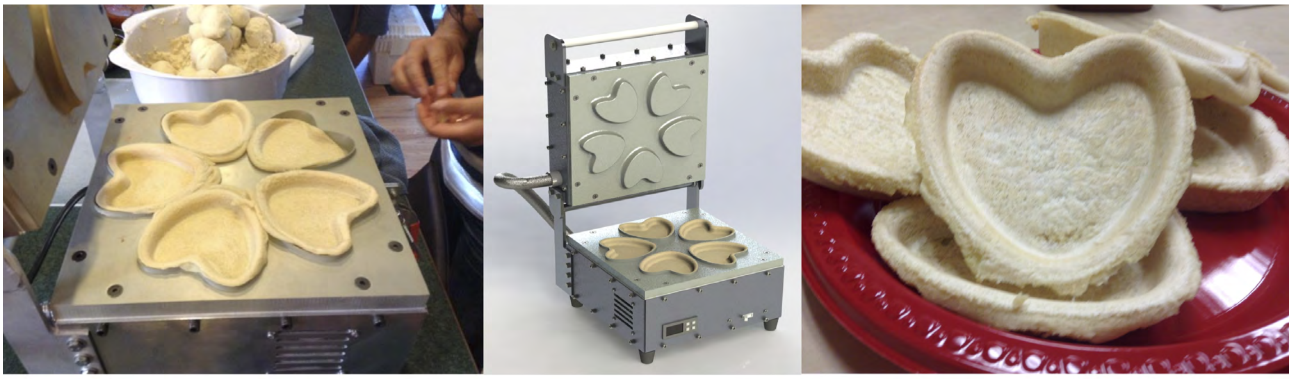

Figure 4: Final design and output

response to the community partners' desire to sell the sopes at a local co-op and at catered events. The sope mixture, which is the artisan portion of the process, did not change.

3.3 Project Outcomes

The sope project impacts can be grouped into engagement, technical innovation, and workforce and economic development categories. Community members are the appropriate evaluators in the engagement category. Feedback from our community partners is summed up in the statement by Monica Ramos, one of the three community partners, during her talk at an outreach and engagement symposium.

> "…before this, I didn't think the university had anything to offer me in my daily life…I felt respected to be viewed as an expert who was teaching people at the university something I could do well and learning from them…my son will come to OSU to become an engineer…" ~ Monica Ramos, community partner (translated from Spanish)

The technical innovation category is evaluated based on how well the engineering specifications were satisfied. The team assessed device weight, device stability (e.g. does it fall over when opened?), and statistical quality control, among others (Table 3).

The workforce and economic development category is divided into workforce and engagement sub-categories. This category is generally a lagging success indicator relative to the success indicators for the engagement and technical innovation categories. The workforce development sub-category is further divided into "university" and "community" categories. Within the university, success is assessed through changes in students' social awareness, their perceptions of the engineering profession and of engineers' social responsibility, and students' actions following participation in the CDTII program. Actions include the type of employment, volunteer activities, or graduate work students select. Workforce metrics within the community include changes in student enrolment in engineering or other higher education programs, the number of jobs created by the community-based start-up company, and the number of individuals trained for positions at the community-based start-up company.

The economic component includes the tax base, median income, migration trends, the number and nature of service-oriented businesses in the community (e.g. proportion of basic grocery and convenience stores to leisure stores). These are lagging indicators because the effects of a successful business venture will not become evident until a number of years after sustained success (e.g. profitability). Business success and expansion could lead to wage increases, higher employment and skill levels, and demand for better services and leisure activities.

There are quantitative assessments of engineering student ethical and social awareness, including the Engineering and Science Issues Test (Borenstein et al., 2010), the Engineering Professional Responsibility Assessment Tool (Canney and Bielefeldt, 2016) and the Community Service

Table 3: Select technical design criteria

Customer criteria	**Result**
Easily carried by one person	Spring scale weight: 19.1 kg (42 lbs), which is below the 22.7 kg (50 lbs) limit
Double the production rate	Up to 100 sopes per hour, compared to the original 20 sopes per hour production rate
Standardised product shape and thickness	Sopes were 0.635 cm (0.25 ± 0.05 inches) thick in 100 sope tests
Reliability	10% defect rate: most ill-formed sopes due to under or overfilling the measuring cup
Tip stability	Device does not fall backward when opened

Table 4: Student comments regarding social consideration

Category	Student Comments
Preconception Awareness	"I have always understood on an abstract level that an engineering degree can be used to help people." "I have thought of using my degree to building reliable energy and water sources for developing countries."
Meaningful Conflict (Dissatisfaction)	"This project opened my eyes to local struggles and local problems." "There was a discernible weight of expectation that put in to perspective the social impact engineering [could] have."
New Concept Acceptance	"The project soon became bigger than a normal design and build project. Interacting with the community demanded our teams full commitment to the success so as not to disappoint and potentially set back the community partner." "The only noticeable difference from the design process [used by other non-CDTII] was that we needed to do some translation from English to Spanish when creating the customer requirements, but other than that [the community partner] has been really understanding about the engineering design process and all the writing that is involved."
Fruitfulness	"I believe that by engaging with the group we were able to learn from them, what responsibilities and capabilities engineers have." "Learning about the impact this project will have in her life and in the life of the other lady involved in this business made me realise that through the use of engineering I can make a great impact on my community." "… we were able to deliver not only a product, but an opportunity into further STEM engagement." "I am honoured to have worked on a project that directly posed a solution to a social and economic problem."

Attitudes Scale (Shiarella et al., 2000). The research team selected qualitative analysis because the goal, at this stage of the CDTII program, is to gain in-depth understanding of the factors that drive success, change, or failure in this context. Future work on larger samples will incorporate quantitative tools. Table 4 contains statements from engineering students who participated in the project.

The research team used the conceptual change model introduced by Mirdad, Hille and Melamed (2015) to qualitatively assess workforce development based on comments made in weekly meetings and in course journals. The conceptual change model (Figure 5) is designed to guide managers or teachers through change implementation (Application Strategy) and assess learner mindset (Condition) during change projects. Stages in the "Application Strategy" are based on existing conceptual change work (Argyris and Schon, 1978, Mazur et al., 2012) that suggests individual behaviour and mindset are true drivers of large-scale change. Single-loop learners gloss over problems by identifying quick fixes or workarounds. They lack in depth knowledge about the underlying process. Double-loop learners, on the other hand, seek to understand why a problem occurred and address the root cause. The conceptual change model was designed to support managers or instructors who wish to guide learners in transition from single to double-loop.

The team assessed the statements based on the culture of disengagement described by Cech (2014). Cech's paper was based on a study of engineering students at four colleges of engineering in the United States. The results suggested that engineering students arrive for their first year with a desire to use engineering for social benefit. They gradually lose this desire as they progress through the discipline.

Figure 6 shows key words used in student discussions about the project. Words in the cloud were collected from student reflections and diary entries. To ensure the cloud reflects students' mindset, community partner names were replaced with "community partner." The team removed words, like "project" that were initially too dominant, as these words masked more meaningful third level words. Finally, plural words, such as "communities" were replaced with singular alternatives, such as "community."

"Community", "impact," "engineering," and "design," are the four most prominent words. Second-level words include "business," and "help." Third-level words include "creating," "believe," and "social." Preliminary analysis

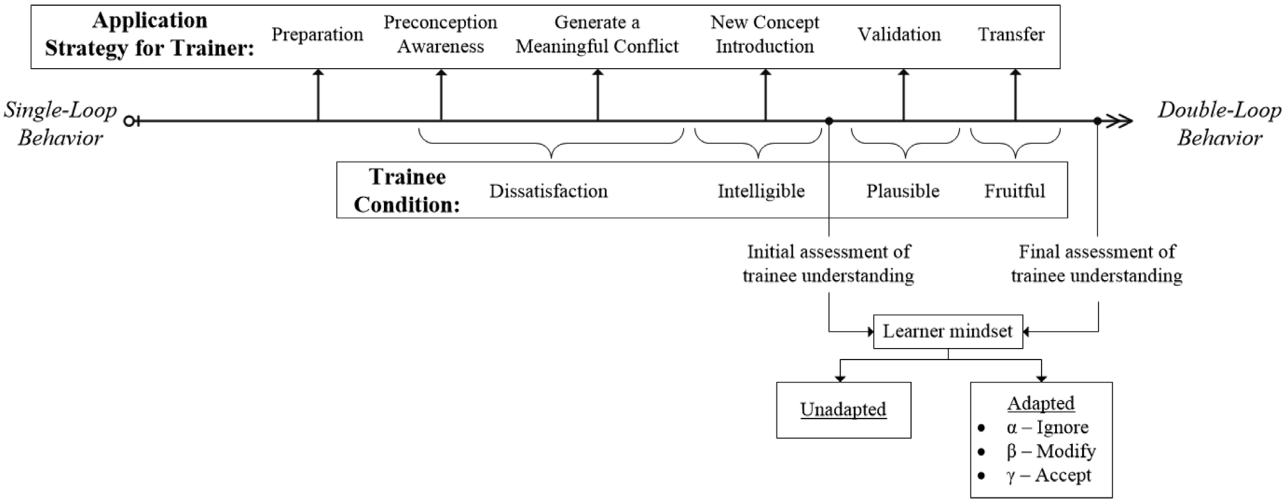

Figure 5: Conceptual change framework (Mirdad et al., 2015)

suggests students understood the socio-economic impact engineering design could have on communities.

On a personal note, one of the co-authors, who was a student in the sope project team, included the following reflection:

> "I was born in Mexico and moved to United States when I was 12. I worked with my father, picking berries at the farms he supervised. He felt I was too young, but I begged him to take me to work because I wanted to help support the family. Working with the Latino community in the farms and meeting a lot of great people through my experiences, I knew I wanted to help the Latino community through the use of my career (engineering). The reason why I selected this project was because I have the connection with the

Figure 6: Word cloud from student feedback

ladies that own the sope business. From my understanding they come from a similar background to mine, and I also want to start making an impact on the Latino community with the use of engineering. I believe this project was a perfect start towards the journey of creating a positive impact on my community.

Thanks to this project, I am thinking about going to Mexico for a few months to work on projects that impact small communities. In the future, I would like to work for a company that invests in projects that impact small communities.”

~Martin Alberto Cortes, fourth-year mechanical engineering student, Oregon State University.

Table 4, Figure 5, and Martin’s statement suggest there might be some self-selection, which is expected at this early stage. In future iterations, the team will also assess “culture of disengagement” conceptual change among students in traditional capstone projects.

4 ACKNOWLEDGEMENTS

The authors thank Loren Chavaria Bechtel, Jeff Sherman, and the Office of the Vice Provost for Outreach and Engagement at Oregon State University. We also thank Monica Ramos and Patricia Rodriquez, our community partners who patiently participated as we learnt to communicate in Spanglish. We also thank the Monroe City council for allowing use of the community kitchen.

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A Taxonomy of Failure Modes of Agricultural Technology Ventures in Developing Countries: Part 1

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ABSTRACT: *Agricultural technologies strengthen and streamline Food Value Chains (FVCs) while improving the lives and livelihoods of smallholder farmers and entrepreneurs. Technologies such as greenhouses, solar food dryers, threshers, grinders, and storage and packaging equipment can help increase the efficiency and sustainability of food value chain activities in emerging economies. However, there are a myriad of technological, infrastructural, and operational challenges that hinder the successful design and sustainable commercialisation or deployment of such products. After over a decade of research, experience, and consultation in the field, we present here an initial taxonomy of potential failure modes during the design, implementation, and maturity phases of agricultural technologies ventures. We argue that consideration of these failure modes early in the design process will assist agricultural technology designers and entrepreneurs in avoiding pitfalls later in the venture lifecycle. Part 1 (of 2) in this article series presents this rationale and development as well as the early, design-phase pitfalls. Together with Part 2 (implementation and maturity failure modes), this taxonomy aims to inform innovators and entrepreneurs seeking to launch successful and sustainable agricultural technology ventures in the developing world.*

KEYWORDS: gricultural technologies, failure modes, food value chains, humanitarian technologies, social ventures

1 INTRODUCTION

Converging global trends such as population growth, desertification, and urbanisation have threatened global food security: the accessibility, usability, and availability of food. Despite these and other challenges, the Food and Agriculture Organization (FAO) of the United Nations states that our planet can support the caloric needs of far more people than current practices allow. Achieving this greater efficiency will require maximising the productivity of land through optimised labour practices, crop yields, water conservation, and waste reduction (OECD-FAO, 2012). It will also entail mitigating two of the most egregious impediments to food security: food waste and loss. Approximately one-third of the world's food produced for human consumption (1.3 billion tons) is wasted by consumers or lost along the supply chain each year (Gustavsson, et al., 2011). In developing countries, nearly 40% of food losses occur after harvest because of premature harvesting, unsafe handling and processing, a lack of processing capabilities, or poor storage facilities (Gustavsson, et al., 2011). The food lost during this process could theoretically feed an additional 48 million people if it were sufficiently preserved and distributed (World Bank, 2011).

Food Value Chains (FVCs) encompass a host of activities across six phases: agricultural production, processing, storage, marketing, distribution, and consumption (Contractor and Lorange, 2002). Figure 1 summarises various examples of agricultural technologies at different phases in the FVC. The adoption and use of such agricultural technologies can strengthen and streamline each phase, resulting in more efficient land use, increased productivity, and a reduction of food waste (Contractor and Lorange, 2002).

The process of realising these FVC efficiencies and facilitating sustainable development is not straightforward, however. There are myriad technological and non-technological issues, some common to other business types and socioeconomic environments, and some specific to FVCs and/or emerging economies. Key to many of these issues are the roles and agency of target market smallholder farmers and fledgling entrepreneurs. Many of these individuals are part of what is sometimes called the "base of the pyramid": the over 3.7 billion people around the world who live on $8 USD per day or less. Over 70% of this base relies primarily on agriculture for their livelihoods, and could potentially improve and benefit from successfully implemented FVC technology ventures (World Economic Forum, 2009; Barrett, 2008).

The taxonomy presented in this article series examines many challenges these local innovators and their governmental, non-profit, private and/or foreign supporters must overcome. Our concentration here is on failure modes in the design, implementation, and maturity phases of the technology venture lifecycle, but it is understood that further socio-political and other challenges must also then be overcome in order to realise systemic improvements. Broadly developing and implementing the best practices in different challenging environments will help build networks and foundations that can support more of these systemic changes.

Despite the collective need and potential agency of farmers and entrepreneurs at the base of the pyramid, most modern FVC technologies are currently disproportionately designed for, and used by, large farming operations. This creates a positive feedback loop where farmers with more resources also have exclusive access to advantageous technologies that increase profits (Barrett, Reardon, Webb, 2001). Increased profits allow wealthier farmers to access other assets, such as financial and marketing services, that are generally unavailable to smallholder farmers. Smallholders are thus in dire need of effective agricultural technologies that they can access without the financial capital that comes from higher returns. For example, empirical evidence has shown that the lack of access to agricultural technologies is one of the direct market barriers for smallholder farmers in rural Africa (Barrett, 2008).

Successfully equipping smallholder farmers with affordable agricultural technologies can dramatically improve their livelihoods while bolstering the resiliency and sustainability of FVCs. With proper socio-political and economic facilitation, this can also create ripple effects of attractive benefits throughout local, regional, national, and even international markets (Barrett, Reardon, Webb, 2001). Fortunately, these opportunities to effect larger systemic change have not gone unnoticed by many both within and outside of emerging economies. Countless entities from governments and non-profits to local entrepreneurs to large corporations are working on technology, education, business, and policy solutions to empower smallholder farmers. Their motivations span a spectrum

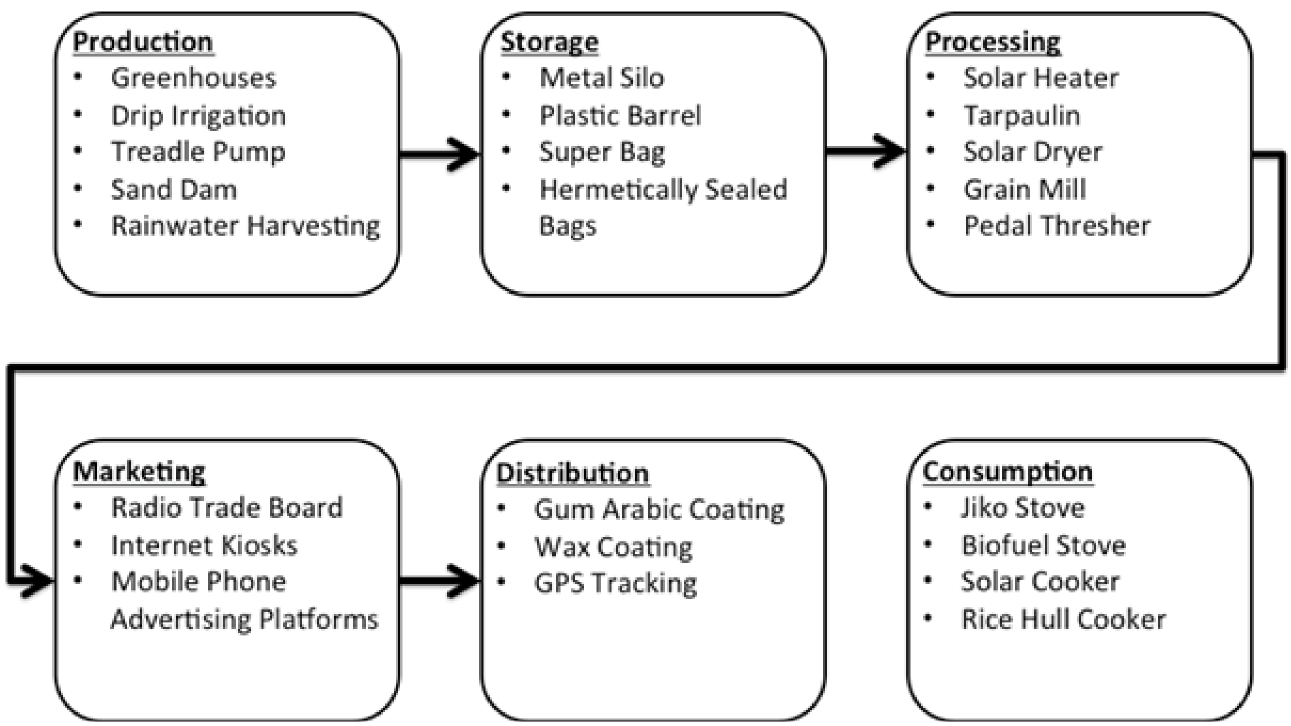

Figure 1: Simplified Food Value Chain with examples of relevant technologies

from humanitarian concern to entrepreneurial opportunism, and their results span from frequent failures to impressive success.

One of the key takeaways from these initiatives is that traditional top-down policy approaches have not succeeded in substantially increasing market participation from smallholder farmers and reducing poverty levels (Barrett, 2008). Similarly, even though a variety of technologies have been developed to improve each phase of the FVC, many of these technologies have failed to reach the target customer segments or to have the desired results. Traditional dissemination methods such as donating technologies to low-income communities are not consistently successful. This is often because donors overlook how technologies will or will not fit into the recipients' specific social, political, geographic, economic, and cultural contexts (Polak, 2008). Commercialisation addresses some of these challenges when it creates a sense of ownership engendered in paying customers and the tangible material value being created for all stakeholders (USAID, 2011). Other trends are less clear, however, and like all ventures, many commercial initiatives also fail. Commercial efforts in emerging economy FVCs can and have included both large corporations and local base of the pyramid entrepreneurs, as well as collaborative or independent efforts with non-profits and governments. These efforts also span a variety of sizes and origin countries, and if their successful practices are harnessed and shared, they have the potential to empower smallholders, entrepreneurs, and FVC stakeholders throughout the world.

Identifying and generalising successful practices in entrepreneurial agriculture technology ventures is not straightforward, however. These commercial ventures face enormous technological, financial, organisational, socio-cultural, and political obstacles at every step of their entrepreneurial journey (Contractor & Lorange, 2002). Just like technology ventures in the Western world and those of other industries, the majority of such endeavours in the developing world do not succeed in becoming independent economically sustainable enterprises. Fewer still can reliably achieve the livelihood goals discussed in this article. Rigorous academic research to support these (small, medium, and large) entrepreneurs on the ground is sparse but gradually growing. Previous works have identified abiotic (external) stressors for such ventures and proposed typologies of business models aimed at overcoming barriers and accelerating technology dissemination (Suffian, et al., 2013). Whilst several studies have articulated challenges faced by entrepreneurs on specific aspects of ventures (e.g. appropriate design, access to capital, manufacturing methods, grassroots marketing) and offered constructive advice, this study aims to initiate a broader discussion of failure modes across the entire lifecycle of agricultural ventures.

"When, why, and how do agricultural technology ventures in the developing world fail?" is the question this article series attempts to answer. We present failure modes in the design, implementation, and maturity phases (the latter two in Part 2) of agricultural technology ventures. These failure modes are derived from narrative review and analysis of several data sources over a three-year period. These multi-faceted sources have been synthesised into a broad taxonomy of failure modes. This taxonomy is intended as a starting point for further discussion rather than as a comprehensive or definitive answer to the goals of stronger FVCs and enhanced livelihoods discussed above.

2 METHODOLOGY FOR TAXONOMY DEVELOPMENT

There are many aspects to the nature of entrepreneurial development that are not best captured through traditional methods of research. Successful ventures often employ an iterative approach to perfect their products and processes; however, there is limited literature on the initial iterations that were ultimately unsuccessful. There is even less documentation on ventures that completely failed. Most of these discussions of failures still take place in informal spheres, where entrepreneurs pass along their experiences directly to likeminded individuals. Often this is appropriate, as FVCs are complex and attempts at formal or prescriptive conclusions require caution (Gomez, et al., 2011). Intergovernmental organizations including the World Bank and Organisation for Economic Co-operation and Development have published useful guidance, though primarily on a governmental policy level (World Bank, 2010; FAO, 2014; World Bank, 2014; OECD and World Bank, 2015). The taxonomy presented here is based on input from and is intended for both local entrepreneurs and more traditional external, large, and/or governmental actors. Our goal in presenting this taxonomy is to drive further formal discussion at the intersection of academia and the world of entrepreneurship, both for content and for proposed systematic methodologies of analysis. For this initial taxonomy, we have leveraged a variety of sources but present no definitive methodology for analysis.

A collection of interviews, personal accounts, and online journals provided crucial content to develop this initial taxonomy. Literature reviews, field experiences, and informal interviews with professors and practitioners from numerous universities and organizations in the United States and Kenya helped us develop a two-pronged approach for this study. First, we studied the business models of 120 agricultural technology projects/ventures using Osterwalder and Pigneur's Business Models Canvas (Osterwalder, 2010). Second, we conducted 512 semi-structured interviews with smallholder farmers, agricultural technologists, entrepreneurs, commission

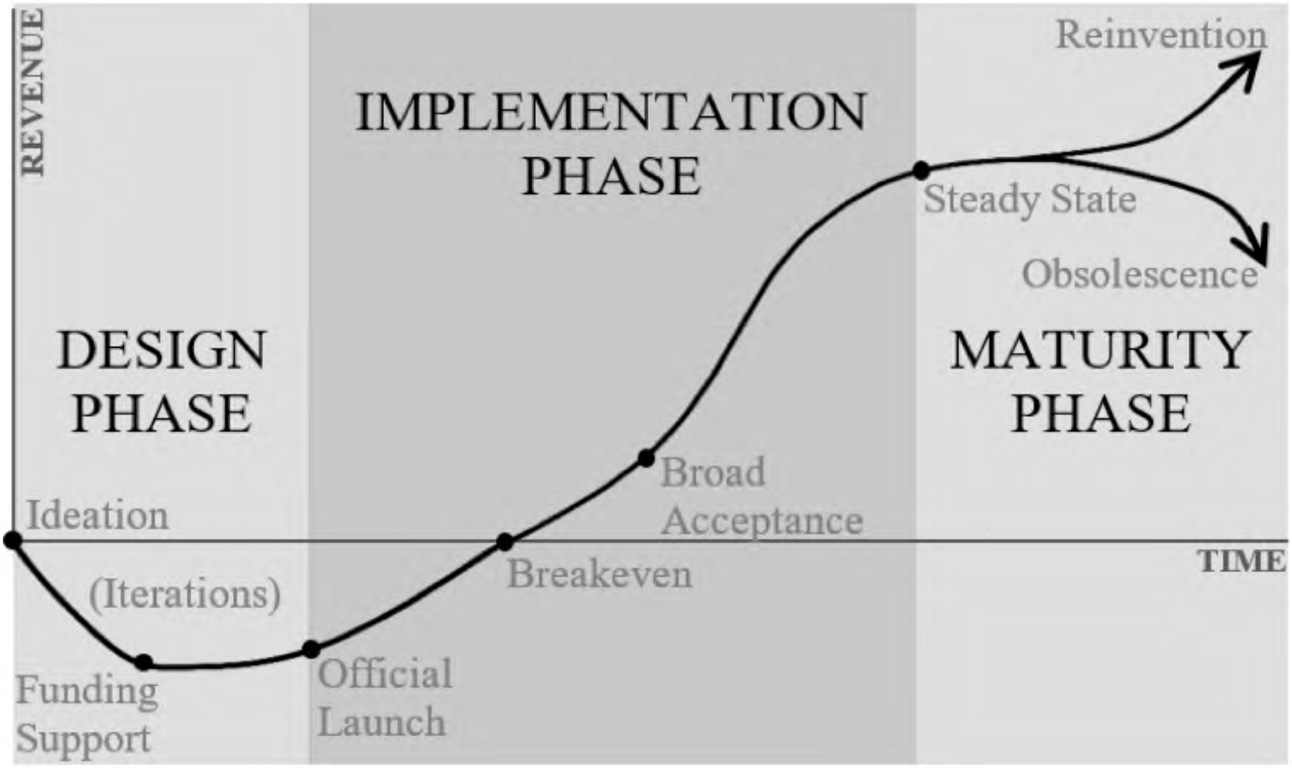

Figure 2: Venture Lifecycle – Design, Implementation, and Maturity Phases. Adapted in part from Norman, 1998. (Maley, Perez, and Mehta, 2013.)

agents, exporters and other food value chain (FVC) actors in Kenya, Cameroon, Rwanda, and Sierra Leone. These particular countries were implicated because our academic program at the Pennsylvania State University engages in entrepreneurial ventures related to food security and pre-primary health care in these countries and has an extensive local network. Collecting, analysing, and synthesising this multi-modal data was a three-year effort that culminated in the development of the taxonomy of failure modes presented here. This taxonomy is not a strict formula, but rather an interconnected web of knowledge to facilitate a discussion of strategies for overcoming common and uncommon agricultural technology venture challenges.

Due to the wide variety of experiences ventures face over their lifetime, failure modes were categorised across three phases: the design, implementation, and mature business operations phases (Figure 2). The design phase starts with ideation, encompasses validation and iterative field-testing, and culminates with the launch of the product or service. The implementation phase is the extremely iterative and chaotic journey from product launch to having strong market presence. Finally, the maturity phase focuses on sustaining business operations and ends in either obsolescence or reinvention. The criteria for transitioning into these phases are difficult to pinpoint and depend on case-specific variables (Maley, Perez, and Mehta, 2013). Despite this caveat, the phased approach added structure to the taxonomy and reduced confusion. It further strengthened the premise that, to be successful, a venture must consider challenges across its entire lifecycle at the onset of the venture.

This taxonomy is a dynamic and evolving framework and not a final and irrefutable list. Some of the failure modes are already sub-categorised further to illustrate their complexities. We expect this process to continue with increased specificity. Further, while the failure modes themselves are distinct, it is important to note that any given example of a failure can and should be traced to multiple failure modes. This means that a generalised taxonomy of modes is at least one level of abstraction above actual examples. (Numerous examples are available in the web-based design tool, while these manuscripts focus on broader-level overviews.) In addition, even addressing the abstracted and interconnected modes is not intended as a concrete strategy to ensure venture success. Instead, practitioners should use consideration of failure modes to engender a better-informed and rigorous design process that can lead to the development of sustainable and scalable ventures.

3 FAILURE MODES DURING THE DESIGN PHASE

Figure 3 summarises failure modes that agricultural technology ventures might encounter during the design phase: from conceptualisation through validation, field-testing, and product launch. Some issues like complexity, manufacturability, and usability are related to the designers and the design process while others like culture, context, and failure to meet a need, are more related to the context of the venture. There needs to be a strong fit between these two, including context-specific experience on the developer team, to fully address the interconnectedness of these failure modes. In particular, note that while many of these modes are explained in terms of non-native developers needing specific knowledge, many potential pitfalls can be mitigated up front by co-creating with local entrepreneurs and technologists who understand this valuable and often latent information.

3.1 Failure to Meet a Need

An agricultural technology is designed to perform a specific task(s) for a specific need. However, designers often face a gap between their perceptions and end-users' actual needs. If end-users are not directly engaged in the design process, the venture risks designing a product that does not adequately meet the needs of its target market. Whilst there are many specific needs not being met, the most common issues in our study were around failure to meet manifest and latent performance needs (product underperforms) and failure to meet customers' needs in terms of payback periods.

- *Failure to Appropriately Address (or be Perceived as Addressing) Real Problem:* While developers must be careful to set realistic goals, many ventures fail because they simply are not seen as useful by the target market. This may be because they misidentify a problem and/or because they inadvertently interfere with a different need. Sometimes the latter can be entirely

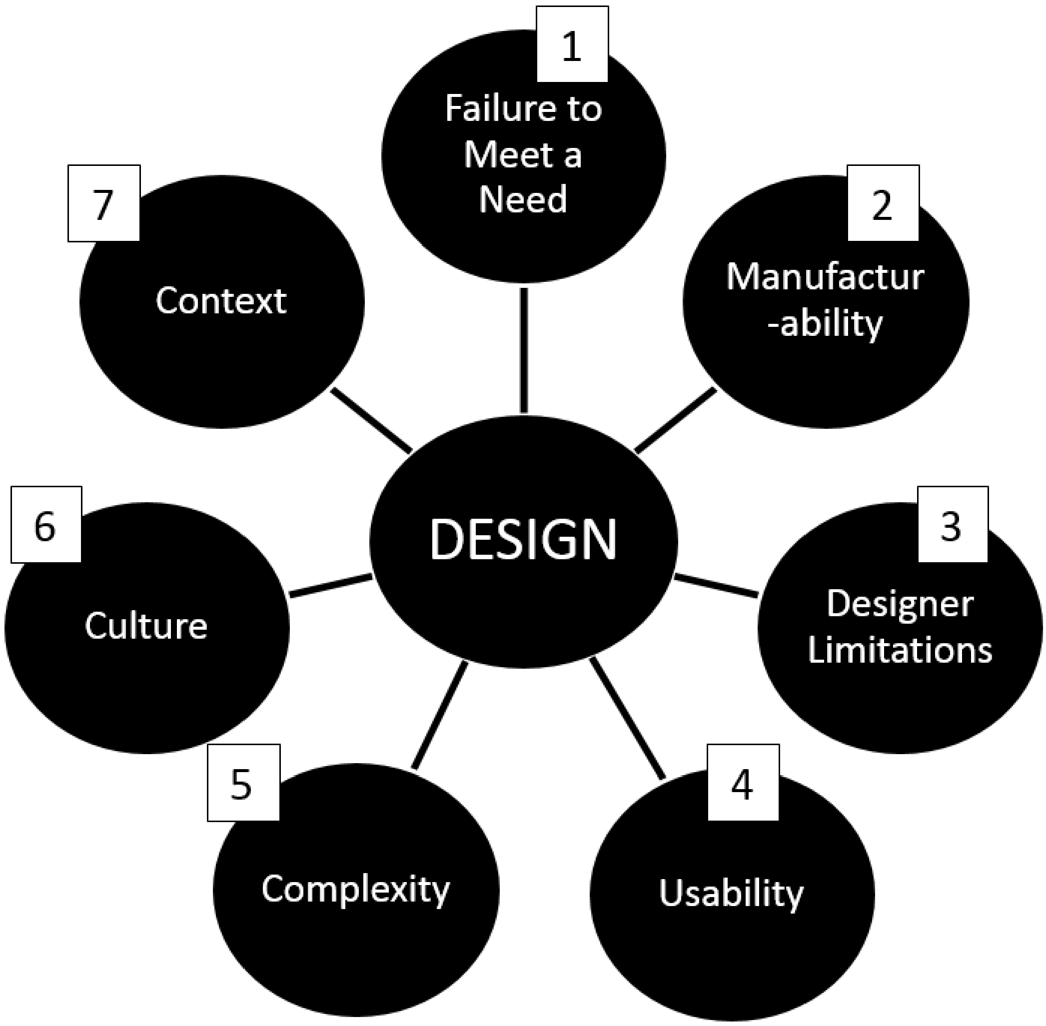

Figure 3: Challenges encountered by agricultural technology ventures during the design phase

unexpected—foot-pedal water pumps needed to be specifically designed to avoid what some communities perceived as inappropriate motion in women's hips (Russel, 2004). Alternatively, ventures that address symptoms may be out-manoeuvred by another that addresses the root issue: a sort of "faster horse" syndrome where one venture is trying to breed faster horses while another is inventing the automobile (Vlaskovits, 2011). Practitioners must remain adaptable and aware of their competitive environment, starting in the design phase but continuing throughout the venture lifecycle. Separately, some ventures can be economically sustainable with customer acceptance but may fail along other metrics important to FVCs, such as environmental or health sustainability (e.g. starting an food cart venture that serves unhealthy rather than healthy foods).

- *Poor Return on Investment:* Many agricultural technologies, such as greenhouses or food dryers, require an upfront investment. Such ventures need to understand their target customers' purchasing power, desires, and risk tolerance. A hefty investment is particularly difficult for rural farmers in developing countries who have limited access to financing and tend to be more risk averse. Many ventures fail because they do not design their ventures for reasonable price targets, reasonable return on investment (ROI) periods, economically appropriate business models, and/or risk-averse messaging approaches. For instance, some successful ventures attempt to drive down their capital price by offering smaller or de-featured technologies that can then be upgraded based on the smallholders' initial revenue. Others try to develop business models in which customers with more disposable income (and therefore also usually more risk tolerance) support the start and scale-up of the entrepreneurial venture, which can then drive down its prices for base of the pyramid customers. Sometimes sales to more affluent customers can even directly subsidise sales to target smallholders—which creates potentially the opposite ROI problem. This problem, also seen in donating technologies directly, occurs when the end-user does not have a large enough stake (not always monetary) in the technology and thus often does not use, learn, and maintain it long-term. As these examples allude, determining an actual return on investment for a specific target user is very complicated and involves far more than just the design phase. However, it should be considered from the very beginning (design phase) of a venture and then subject to constant evaluation throughout the lifecycle. This is true of other failure modes as well, but ROI is notably complex.

3.2 Manufacturability

Manufacturability refers to the specific process by which a product is physically assembled. It is essential for a venture to consider manufacturability early in the design process (Dzombak, Mehta, Butler, 2015). Of several issues related to manufacturability, the three most common failure points relate to:

- *Inconsistent Manufacturing:* Many ventures fail due to an inability to consistently manufacture and deliver products that their customers expect, e.g. due to variations in production costs or lead times. This type of inconsistency is particularly damaging when working with highly risk averse customers, and many ventures do not recover from this damage to their brand (or even from perceptions of past ventures' failures). Incorporating technical quality assurance and societal trust management can be critical in these cases.
- *Lack of Local Spare Parts:* The availability of local spare parts is an important design consideration, and many target communities have limited infrastructure for repairs. Thus, instead of attempting to adapt designs from more industrialised environments, we suggest studying highly successful ventures that deliberately designed around locally available spare parts and human resources. A key exemplar from outside of agriculture is NeoNurture's baby incubator made from car parts (Schultz, 2010).
- *Lack of Human Resources:* Specific human resources are required to construct, install, repair, and/or maintain agricultural technologies. While the workforce can be developed over time, this with limit initial implementation and growth, and attrition rates amongst well-trained workers are fairly high. Venture developers should be very aware of the specific human resources available in their context, and it can help to be engaged with local training institutions as well.

3.3 Design Limitations

Issues ranging from material selection, infrastructure, and repair protocols are examples of the kind of design constraints that vary widely in emerging economies and affect far more than manufacturability. It is imperative that a venture has designers with relevant experience and expertise in designing products for resource-constrained settings and the specific target market in particular. A designer must be able to accurately incorporate the abilities of, and resources available to, the end-users. Ventures are likely to fail when they employ designers without the necessary experience designing for their context.

3.4 Usability

Assumptions regarding end-users' abilities, backgrounds, and expectations for easily using a product should only be made carefully and must be tested early. Designers must be particularly careful with technologies for specialised fields (e.g. welding) to ensure that early usability testing is accurate enough to inform design iterations. These usability issues should also be examined for a technology's manufacturing process (from the point of view of those who will produce it). Ventures fail when they make and then do not test and iterate inaccurate assumptions.

3.5 Complexity

Complexity is a measure of the number of components or connections necessary to make a product work. Simple and focused technologies are more likely to succeed than products that provide features of secondary interest and more complexity. This is also true of a technology's manufacturing process itself: a simple output technology whose production is complex or difficult to use suffers the same problems as a complex technology. Ventures fail if their technology is too complex to be manufactured, assembled, and readily used and maintained by their customers or other stakeholders.

3.6 Culture

Every culture is unique in various capacities, and this is a very broad failure mode category. Designers must determine the compatibility of their technology with the culture of the end-users. We found the most critical considerations to include:

- *Lifestyle of End-Users:* Ventures fail if their product is incompatible with the lifestyle of their customers. Some aspects of the end-users' lifestyle will naturally change over time; however, it is unrealistic to expect a smallholder farmer to make a significant change in order to use a novel product or service. It is much more promising to begin the design process from the perspective of the users' current lifestyle and expectations. The potentially wide variation in lifestyles across a market based on class, geography, and background is also critical. It necessitates appropriate and sometimes diverse engagement strategies throughout the entire user journey (marketing, sale, delivery, product design, customer support, etc.). Alternatively, venture practitioners should always consider whether they need to decrease complexity by limiting their initial target market. (De-scoped segments can be served as a venture scales up or with other ventures more specific to their needs.)
- *Societal Norms:* Societal norms are group-held beliefs about how members should behave in a given context. The expected behaviour of targeted customers, including gender or age-specific expectations, is extremely valuable information for agricultural technology ventures. Such knowledge can allow a venture to appropriately position itself for maximum impact throughout the design phase and the entire lifecycle.
- *Traditional Agricultural Solutions:* If a traditional solution is adequately addressing the issue—or is perceived to be—there is no incentive to adopt a new technology. This also implicates the need for product outreach if the technology is improving upon a traditional practice.
- *Perception of Product:* Various characteristics such as country of origin or the selected materials of an agricultural technology directly affect its perception in a specific culture. For example, a product designed by a German company may have a different perception than a product designed by a Chinese company depending on the target market and its societal history. The perception of such characteristics varies greatly across different regions and cultures and should be investigated carefully.

3.7 Context

A designer must understand the parameters within which their product and venture will operate. This entails recognition of the overarching cultural, technological, and social constraints and implications of the target market. This comprehensive design category intersects with many of the other categories, but also covers region-specific sub-categories:

- *Topographical and Edaphological Factors:* Topography refers to the physical contours of a location, and edaphology refers to the how soil influences people's use of land for plant growth. A region's topographical and edaphological characteristics determine the agricultural potential of that location. Thus, agricultural technology ventures must understand these factors to validate the need, appropriateness, and viability of an agricultural technology in a given context.
- *Infrastructure:* Infrastructure in developing countries is often a challenge for prospective ventures, particularly in rural areas heavily involved in agriculture (Barrett, 2008). Challenges manifest in many different ways throughout the user journey, starting with limited communication and marketing opportunities to potential consumers. The "last mile" problem, in which poor infrastructure makes the last mile of distribution significantly more difficult and less efficient, also challenges the economic sustainability of supply chains. In addition, smallholder customers cannot leverage improved infrastructure (e.g. electricity) to use some potential technologies. Ventures fail when

they do not understand and plan for context-specific infrastructure challenges.

- *Political Issues:* The type and nature of the political system affects many aspects of agricultural technology ventures. For example, starting a venture in a fledgling democracy like Kenya presents vastly different challenges to that of a venture working in a failed state like the Democratic Republic of Congo. Ventures will fail if they do not understand the relevant political issues, for example the process (or lack thereof) of receiving necessary governmental permissions, following tax codes, and handling varying forms of corruption.
- *NGO Presence and Activity:* Areas without effective NGOs can lack the essential partnerships necessary to facilitate growth and lead to successful implementation. Conversely, too many NGOs in a given region can inhibit scalable impact and also lead to failure. The effect of NGO presence and activity can be anticipated by researching the reputation and impact of local organisations and how people perceive local NGOs.
- *Regulatory Frameworks:* Regulatory frameworks can cause a venture to become unrealistic or far too costly. For example, Rwanda’s strict regulations on imported plastic constitute a challenge to ventures that needs to import plastic for their product. Regulatory frameworks can also provide ventures with credibility and customer trust if they are not too troublesome, but this also depends on consumer relationships with and perceptions of their governmental agencies.

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A Taxonomy of Failure Modes of Agricultural Technology Ventures in Developing Countries: Part 2

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ABSTRACT: *Agricultural technologies strengthen and streamline Food Value Chains (FVCs) while improving the lives and livelihoods of smallholder farmers and entrepreneurs. Technologies such as greenhouses, solar food dryers, threshers, grinders, and storage and packaging equipment can help increase the efficiency and sustainability of food value chain activities in emerging economies. However, there are a myriad of technological, infrastructural, and operational challenges that hinder the successful design and sustainable commercialisation or deployment of such products. After over a decade of research, experience, and consultation in the field, we present here an initial taxonomy of potential failure modes during the design, implementation, and maturity phases of agricultural technologies ventures. We argue that consideration of these failure modes early in the design process will assist agricultural technology designers and entrepreneurs in avoiding pitfalls later in the venture lifecycle. Part 2 (of 2) in this article series presents the implementation and maturity-phase failure modes. Together with Part 1 (taxonomy development and design phase pitfalls), this taxonomy aims to inform innovators and entrepreneurs seeking to launch successful and sustainable agricultural technology ventures in the developing world.*

KEYWORDS: agricultural technologies, failure modes, food value chains, humanitarian technologies, social ventures

1 INTRODUCTION

This two-part article series presents the rationale, initial development, and a preliminary taxonomy of failure modes of agricultural technology ventures that support and strengthen Food Value Chains (FVCs) in developing economies. The taxonomy presents failure modes across the design, implementation, and maturity phases of the venture lifecycle. While part 1 focused on failure modes in the design phase, part 2 (this article) presents common failure modes in the implementation and maturity phases.

2 FAILURE MODES DURING THE IMPLEMENTATION PHASE

Figure 1 summarises potential failure modes during the implementation phase of the venture: from product launch to establishing strong market presence. The duration of this phase varies from a couple of years to a few decades until the product gains traction and the venture finally has reliable and sustainable revenues. Challenges during this phase can be classified as either internal or external. External issues (1 to 6) are those that deal with stakeholders and entities outside of the organisation delivering the product or service. Internal issues (1 and 7 to 12) all occur within the organisation, either with the product itself or the employees and organisation necessary to deliver the product.

2.1 Access to Capital

A designer must understand the parameters within which their product and venture will operate. Ventures need start-up capital. At the same time, their customers also need capital to purchase the products. For both entities, finding financial resources is often difficult.

- *Internal Access to Capital:* A new venture must have sufficient capital to cover the start-up and

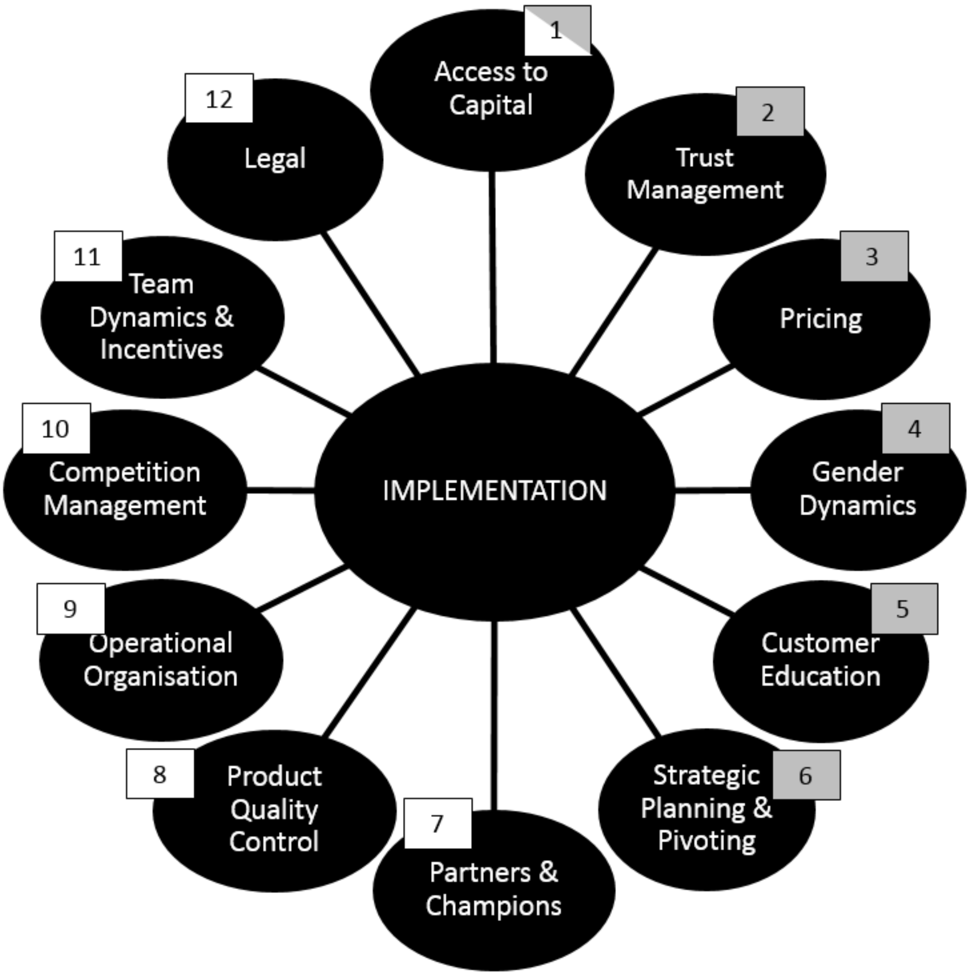

Figure 1: Challenges encountered by agricultural technology ventures during the implementation phase. Grey boxes (1 to 6) indicate external challenges whilst white boxes (1 and 7 to 12) are internal.

implementation costs. It is important to have an accurate estimation of the necessary costs to bring a venture to the launch stage of the venture lifecycle. It is common for ventures to grossly underestimate the time it would take for them to gain traction and have a cash-positive revenue model. In other words, even after product launch, ventures may need loans and equity for several years or even decades. Ventures fail when they are not able to demonstrate impact and continuously raise funds over an extended period of time and/or when they aim 'too big' initially instead of prioritising achievable commercial or fundraising sustainability.

- *External Access to Capital:* In the developing world, the majority of farmers are smallholders. If a farmer wants to purchase a new agricultural technology to improve their livelihood, they need seed funding. Traditional seed funding comes from a combination of personal savings and/or family, friends, and neighbours. An agricultural technology venture needs to develop avenues and channels that will allow farmers to reach their product. One option is working through the financial sector, by building relationships with Savings and Credit Cooperative Organisations (SACCOs), Micro-finance Institutions (MFIs) and other actors in the informal lending space. Other actors such as non-government organisations (NGOs) and governments can also help, but implementation failure can also result from donating products to end-users who have no financial stake or other sense of investment. Ventures thus fail when they do not establish partnerships or other avenues for customers to access capital and invest in their products.

2.2 Legal

Ventures encounter a multiplicity of legal issues in formal legal spheres and grey areas when they function in the informal economies of developing countries.

- *Informal Legal Issues:* In most developing countries, a large portion of the economy is run informally. Many small businesses and enterprises operate successfully despite remaining officially unrecognised by the government. Formalising a business tends to be an expensive and time-consuming process that may not be feasible or realistic during the start-up phase. However, operating in the informal sector exposes ventures to legal risks as they grow. Every venture has to decide at what point during their lifecycle they must formalise their business. Ventures that formalise their organisations too soon fail when they are unable to pay hefty taxes and bribes and meet stringent import regulations that their informal competitors do not have to. At the same time, ventures that stay informal for too long also encounter legal troubles (like tax evasion) and have the added disadvantage of not having a disciplined and structured entity to make important operational and financial decisions or access capital from the formal lending industry.

- *Formal Legal Issues:* There are specific challenges to consider once a venture is operating in the formal economy. Examples of such issues include: taxes, employment regulations, regulatory frameworks, and intellectual property laws. A thorough understanding of the relevant formal legal issues will assist ventures in avoiding costly litigation. The legal and ethical burden is often higher for ventures operated by foreigners, and this increased scrutiny necessitates clear operations from a legal perspective. Additionally, when ventures need to conform to the laws and norms of the developing country where they operate as well as of a different (often Western) country where they receive funding, the legal burden is doubled.

2.3 Pricing

Choosing and adapting optimal price points is a complex task that is influenced by the competitive landscape, local partnerships, and customer perceptions.

- *Competitive Pricing:* Agricultural technology ventures must accurately estimate the demand and value of the product in the target marketplace. Pricing the product too high makes it unaffordable to customers and is a common failure mode. At the same time, products have also failed because they were priced too low and could not sustain their costs or were perceived as inferior to other options.
- *Subsidies:* Subsidies provided by government agencies or NGOs can help ventures bridge the gap between the product costs and the price point that their customers can truly afford. The obvious problem is the development of a black market around the product with customers reselling their products to turn a quick profit. Also, subsidies are not sustainable in the long term. This study encountered several ventures that heavily subsidised products to demonstrate demand and boost sales numbers for marketing and fundraising purposes. This created an artificial demand for the product, which was either sold for a profit in different regions or was misused, with the ultimate result being the venture's downfall. Similar situations arose when ventures were not able to make the jump from subsidised rates to regular rates for the products because people were expecting to pay the subsidised price.

2.4 Gender Dynamics

In many non-western societies, gender roles and norms can be different and stricter and hence necessitate a greater level of attention. The roles are derived from cultural perspectives and societal norms and have direct implications on lifestyles. Ventures that do not understand these implications will struggle to develop appropriate dissemination strategies, in terms of marketing, sales, and follow-on support. Gender dynamics can also influence financing strategies for ventures. For example, women in some cultures avoid borrowing money from friends, neighbours, and relatives. At the same time, many MFIs prefer to lend to women because of higher repayment rates. Women's cooperatives are also popular in some countries' agricultural sectors. Ventures fail when they do not consider gender dynamics in every aspect of the venture, especially during the implementation phases. They must consider not just how men and women will access and operate their product differently but also espouse a systemic view of how that product creates perceived and real value for all users.

2.5 Customer Experience

Some agricultural technologies require a substantial amount of training or experience in order to be operated safely and effectively. Ventures attempting to implement such products must determine what level of training their customers require, and how it will be delivered. Accurate and specific market research and testing is important for making informed decisions regarding the process of customer education. The technology will not be used effectively, and thus not be successfully implemented, if ventures do not adequately educate and engage their end-users. One common sub-mode of failure in this study was that, while ventures tend to do a reasonable job educating their customers when the product is sold, mechanisms for lateral knowledge sharing between end-users that take the specific location and circumstances of the customers into account are rarely developed. This long-term lateral knowledge sharing is often more important than the brief operation and maintenance training provided early on.

2.6 Strategic Planning and Pivoting

Ventures introducing new technology products into a market must be extremely flexible. Properly timed strategic adjustments to the product, marketing strategy, customer base, or the implementation approach can make the difference between reaching maturity and failing to get traction for a venture. Ventures fail when they do not continuously assess what is working and what is not and pivot every necessary aspect of their venture until they are successful. We observed numerous cases of ventures or projects that failed when the team refused to change course despite overwhelming evidence that they were on the wrong track. There were many reasons why teams remained steadfast – they were not responsive to customer feedback, they truly believed that they were on the right track (despite the data indicating otherwise), they were emotionally or financial invested in a certain direction and could not convince themselves to change course, they did not know what new direction to take, or they simply lacked the decision-making structure and strong leadership to change course.

2.7 Partners and Champions

Strategic partnerships and champions help ventures to gain the access, exposure, and credibility necessary to successfully implement a technology in a new region. Thorough market research helps ventures identify the initial partnerships necessary for the implementation phase.

- *Credibility:* If an agricultural technology venture is implementing a product in a new region, it will require key partnerships to initially reach the market and avoid failure. Such partnerships, particularly if the partner is well-established in the individual community, can lend crucial credibility to the new unproven technology. These partnerships can take many forms, including government support, region-specific business endorsements, support from influential local opinion leaders and celebrities, or even symbolic support from a well-known Western company.
- *Community Engagement:* Successfully interacting with the local community at a grassroots level can establish a market presence for a given product. Foreign companies especially require early community engagement to proactively define the perception of the venture. Ventures that have brick and mortar locations with approachable representatives for potential customers can talk to tend to be better received, particularly in rural areas. For low-cost (and hence, low-margin) consumer products, this grassroots engagement strategy is onerous but critical to increasing sales and getting traction.

2.8 Product Quality Control

A lack of reliable manufacturing and distribution channels are two areas that can potentially compromise quality control, particularly in areas with poor infrastructure. As mentioned in Part 1, without consistent product quality, ventures are unable to build the trust in their brand that is important for word-of-mouth marketing and increased sales. This study identified a wide range of quality challenges: locally-assembled products that failed because of worker training and discipline issues; imported farm implements that were of excellent quality in the first shipment but poorer quality in subsequent shipments; and low quality raw materials that negated the good manufacturing practices of vendors.

2.9 Organisational Structure

Ventures that lack clear roles and responsibilities for their employees often fail to operate effectively on the ground. Ventures must identify specific needs and hire the personnel eager and capable of effectively implementing the venture's business strategy. Poor organisation complicates the decision-making process and decreases the odds of successfully navigating the implementation phase. The study identified several instances where the senior manager who was around made decisions for the day, leading to poorly-informed as well as inconsistent decisions. Some companies, especially in Kenya, had fairly elaborate organisational structures and advisory boards with complex rules, guidelines, and procedures. On closer examination and interviews, it was apparent that few of the guidelines were actually followed by the advisory board and decisions were made by 1 to 3 executives without consultation with other senior personnel.

2.10 Competition Management

Agricultural technology ventures encounter many situations during implementation in emerging economies where intellectual property protections are not respected or enforced. In such situations, competition management often involves overcoming challenges from counterfeit designs. This study found examples of many ventures that were unable to understand the competitive landscape of their technology and were eventually completely marginalised in the marketplace by cheap imitation products. A common approach of the counterfeiting companies was to provide higher sales commissions to retailers. Several small companies and vendors recounted instances of customers coming with workmen to study and photograph the technology product and then making it themselves in carpentry or metalworking shops. For more complex products that could not be fabricated by local workers, it took just a few months for cheap knock-offs from "China" to appear. While duplicate products were not always from China, they were always attributed to China. On a different note, technology ventures were often unaware of, or downright ignored, other local firms making similar products. There were a few instances of collaborations amongst competitors but for the most part, the concept of collaborating with a competitor was frowned upon.

2.11 Team Dynamics and Incentives

Intra-team dynamics directly impact the effectiveness of every organisation. In particular, FVC ventures in emerging economies typically involve a diverse set of stakeholders with different levels of engagement and responsibility. In order to optimise team dynamics, a venture must evaluate how each employee contributes to the venture and what their incentives are for this involvement. This study identified a very large number of projects that failed because the team either had internal conflict or a key member left.

2.12 Trust Management

Managing trust between internal and external stakeholders is paramount in developing countries, particularly for ventures championed by people perceived as outsiders. Ventures fail when they do not develop strategic partnerships to build and maintain trust in their brand and technology amongst the stakeholders. Without this trust, customers will not be interested in an unfamiliar product with no local credibility, and the venture may fail during the implementation phase. Trust is paramount in all personal and professional undertakings because farmers as well as micro-entrepreneurs prefer to work with people they know and trust at the expense of reduced profits or new customers.

3 FAILURE MODES DURING THE MATURITY PHASE

Figure 2 captures the failure modes during the maturity phase. While many of the failure modes in the implementation phase are relevant in the maturity phase, seven additional failure modes emerge once the product has an established market presence and steady sales.

3.1 Stakeholder Management

Important decisions must be made regarding the engagement of various stakeholders as a venture evolves. While certain stakeholders may be required during start-up and implementation, they may be unnecessary, or even detrimental, at advanced phases of the venture. For example, while non-profits might be involved in early stages to understand customer needs, field-test new products, and find a product-market fit, manufacturers and distributors assume more importance as the venture reaches steady-state operations. Conversely, expansion of business operations may necessitate additional stakeholders with specific expertise like supplier quality control, risk management, and franchise development. Ventures fail when they don't re-evaluate their stakeholder relationships on a continual basis and take a practical and strategic approach to building and nurturing practical relationships.

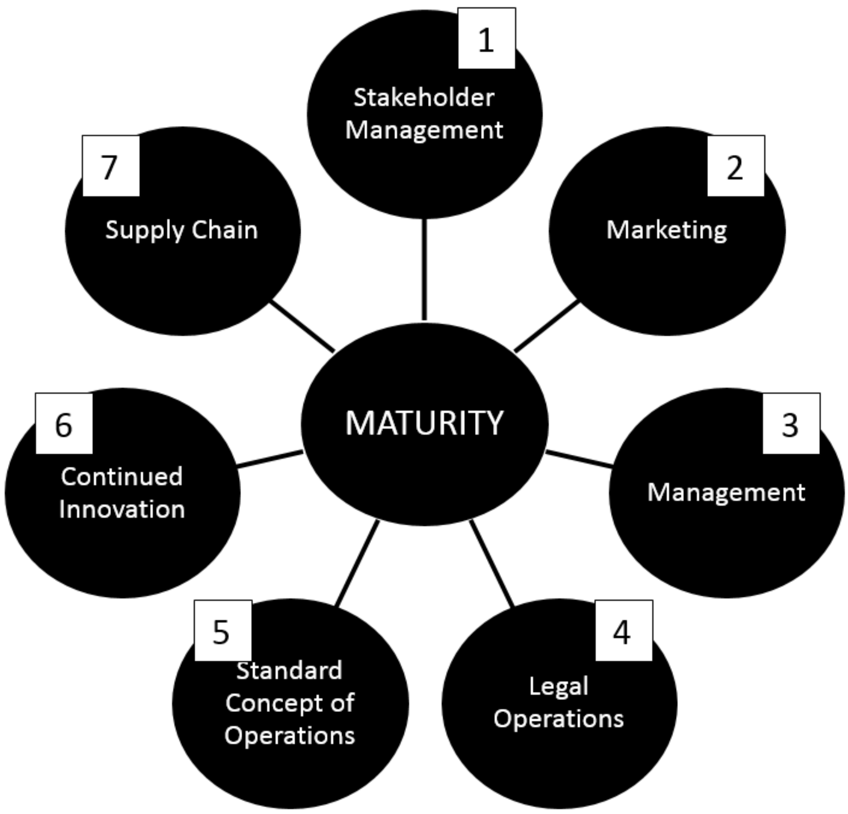

Figure 2: Challenges encountered by agricultural technology ventures during the maturity phase

3.2 Marketing

Marketing can be particularly difficult when the majority of targeted end-users live in rural areas. Non-traditional platforms and channels must be leveraged to consistently reach relatively obscure customer segments. Ventures that rely on traditional Western marketing techniques (e.g. billboards on busy roads or television ads) often fail to reach their customers in rural areas. Furthermore, marketing strategies like these are costly and potentially fatal to a venture if it does not receive a significant return on the investment. This study found that, for many successful enterprises, marketing was intricately connected to developing relationships with customers and empowering them. For example, traditional credit cooperatives were much more successful than MFIs because they employed business development officers whose job was helping communities organise themselves and save money. Social media like Facebook and WhatsApp were incredibly popular and cost-effective ways to reach the urban as well rural customers. Ventures failed because they did not proactively cultivate their markets with practical, long-term, customer-centred approaches.

3.3 Management

The initial management structure used by a venture may not be ideal as the venture moves into the maturity phase. If a venture is seeking to expand to new regions or reach a different market, it should consider the constraints of its current structure and employees. Ventures failed when they did not candidly re-evaluate the goals, team strengths and dynamics, and management styles necessary to sustain and grow the organisation. This study observed numerous cases of failure when the visionary entrepreneur did not empower a management team that was familiar with working in the specific context. On the contrary, a sizeable number of the ventures we studied were started by expatriate entrepreneurs who turned over the keys to a native, and typically much more experienced, management team once the product had significant traction.

3.4 Legal Operations

In all likelihood, a venture in the maturity stage will be operating in the formal economy. This type of operation offers different set of challenges compared to legal issues during implementation. As a venture matures and becomes more profitable, regulatory scrutiny tends to increase, and ventures need to stringently follow local laws related to employment practices, product quality, etc. Emerging economies often experience various disconnects between local laws and operational norms, which presents additional legal challenges to companies. These legal challenges are compounded when ventures have legal roots in multiple countries and must abide with conflicting regulations or by stringent requirements in Western countries that reduce profits in their target market.

3.5 Standard Concept of Operations

The concept of operations (ConOps) explains exactly how a venture will create, deliver, and capture value. This concept of operations inevitably changes and fluctuates significantly during the design and implementation phase. At the point of maturity, however, a venture should have enough knowledge and information to standardise this process. Standardised operations allow for sustainable, reliable, and more efficient products and processes. This process of converting tacit knowledge on every aspect of the venture into clearly documented procedures can be instrumental as the venture evolves and experiences employee turnover. Ventures often failed because they were unable or unwilling to document and standardise this process. As ventures grew and sales increased, they needed more employees dedicated to quality control across the organization and external vendors. These increased overhead costs decreased the profit margins and led to reduced sales.

3.6 Continued Innovation

A mature venture will attract competition attempting to replicate its success. Continued innovation allows a venture to maintain and improve its market share and enhance its competitive advantage. As is the norm in the Western world, ventures failed when they did not prioritise research, development, and continual innovation.

- *Increase Venture Efficiency:* Once in the maturity phase, a venture should have enough data and experience to optimise their process of value creation and delivery. This will maximise productivity and thus profitability. This study found that several ventures failed because they were not responsive to evolving customer needs and did not strive to periodically improve their products and processes.
- *Strategies for Growth:* A venture in the maturity phase should continuously research new market opportunities for growth and revenue diversification. Such opportunities may not have been feasible earlier in the lifecycle, but a mature venture can take advantage of experience and credibility to further expand operations. In the agricultural sector, there are often additional complimentary activities that ventures could perform by expanding into adjacent FVC activities. For example, an agriculture production venture may be able to add value by expanding into processing technologies (e.g. canning or desiccation after production). Ventures that do not strategise for continued growth and innovation consistently lose market share to new competition that is willing to innovate.

3.7 Supply Chains

Agriculture technology ventures operating in the developing world inherently face unique and complicated supply chain challenges. For example, typically the majority of the target market lives in rural areas with poor infrastructure. Such constraints affect the manufacturing, assembly, and distribution of products. These issues are important throughout the venture lifecycle, but ventures can fail during maturity if they are unable to overcome surprise supply chain disruptions, develop backup options, and sustain their operations at scale despite supplier shortcomings. Quality control, management inadequacies, and high transportation costs were cited as major contributors to supply chain irregularities. At the same time, there was wide recognition that improved infrastructure is bringing down transportation costs and evolving educational systems and professional development programs focused on small business are strengthening businesses and supply chains.

4 CONCLUSION

This two-part article discusses common failure modes of agricultural technology ventures in developing countries. Since the development of this taxonomy three years ago, it has been validated by technology entrepreneurs as well as academic experts in several countries across Sub-Saharan Africa and South-East Asia. Nevertheless, this taxonomy will remain a work-in-progress as additional success modes and failure modes are understood, articulated, and integrated. By far, the largest challenge faced by this study was the hesitation amongst entrepreneurs and FVC actors to share their failures and challenges. Building an open culture that celebrates failure just like it celebrates and rewards success will help strengthen this taxonomy and accelerate the design and commercialisation of agricultural technologies to empower the hundreds of millions of smallholder farmers and actors across food value chains in developing countries.

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Assessing the Impact of Durable Flooring Structures on Refugee Sleep Quality and Duration

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ABSTRACT: *Conflict and persecution continue to displace people from their homes adding to an already overwhelming refugee crisis worldwide. Overall, refugee health is difficult to measure objectively and is influenced by a number of factors including transient, and often inadequate, housing conditions. Emergency Floor (EF) is a quickly deployable, lightweight, insulated flooring system intended to protect temporary structures from extreme temperatures and outdoor conditions. A pilot study was conducted in two informal tented settlements in Hermel-Baalbek, Lebanon to assess how installing Emergency Floors in tented shelters impacted sleep duration and quality, indicators of overall wellness, among refugees. A baseline survey was administered, and Emergency Floors were installed in all households in both settlements in October 2016. A follow-up survey was conducted to record outcomes in April 2017. Thirty-four households consisting of 150 individuals participated in the baseline survey. Seven households were were not available for follow-up survey due to moving away from the area. The final sample yielded a total of 27 households and 120 individuals. Results indicated that sleep duration significantly increased, and sleep quality significantly improved after EF installation. Furthermore, respondents reported feeling more comfortable, warmer, safer, and cleaner when sleeping in a shelter with EF installed. These encouraging results suggest an overall increase in perceived well-being. Future research should continue monitoring floors to assess long term wear and explore additional uses for EF in other temporary structures.*

KEYWORDS: flooring, well-being, Lebanon, refugee, sleep duration, sleep quality

1 INTRODUCTION

In 2015, the world population of displaced people reached a record high of 65.3 million people (UNHCRa, 2015). The ongoing Syrian civil war has increased the number of Syrian refugees registered with the United Nations High Commissioner for Refugees (UNHCR) in neighboring Lebanon from 158,973 (January 2013) to 997,905 (October 2017). This makes Lebanon home to the highest number of Syrian refugees per capita in the world (UNHCRa, 2015; UNHCRb, 2017; UNHCRc, 2017). This increase has placed burden on governmental services for refugee aid and caused extensive overcrowding (defined as less than 4.5 square meters per person) in refugee communities (UNHCRb, 2017; UNHCRc, 2017). The "no-camp policy" adopted by the Government of Lebanon has led to refugees forming small informal tented settlements, where about 17% of the overall displaced population reside (UNHCRc, 2017). Though these ad-hoc communities do not consist of a large number of tents overall, overcrowding within households is common (53%) and many shelters suffer from dangerous structural conditions or urgently needed repairs such as weatherproofing (UNHCRb, 2017; UNHCRc, 2017). Overcrowding paired with dilapidated tent condition can lead to uncomfortable living and sleeping conditions, especially during cold winter months.

Previous research has demonstrated that decreased sleep quality and duration are related to numerous relevant public health outcomes in the general population (Altevogt and Colten, 2006). Specifically, poor sleep quality has been linked to adverse mental health outcomes including increased levels of depression, anxiety and stress as well as physical maladies such as type 2 diabetes and even mortality (LeBlanc, 2007; Augner, 2011; Cappuccio et al., 2010; Tamakoshi and Ohno, 2004). Insufficient sleep can also negatively affect an individual's ability to adequately complete tasks and contributes to many work-related injuries (Strine, 2005; Lombardi, 2010). This is particularly applicable to refugees, who are often in debt and lack steady job-related income (UNHCRc, 2017). Additionally, since refugees tend to share resources within their communities as part of a collective coping mechanism, stress, anxiety, and depression resulting from poor sleep can potentially increase conflict between community members and harm the community's social structure (UNHCRc, 2017).

As most sleep-based research has been conducted under controlled settings in developed countries, rather than in conditions resembling refugee camp living conditions, the conjecture that lack of sleep from uncomfortable living conditions can negatively affect overall well-being is generaliszable to the refugee population. The association between sleep and numerous aspects of health make it an area of research that is ripe for further investigation.

The relationship between housing and health outcomes has been well-researched and includes direct factors such as location, building materials, overcrowding, access to water and sanitation, and ventilation (Al Khatib and Tabakhna, 2006). Many current temporary refugee shelters only have thin plastic sheet laid over the ground. This provides only minimal protection from the outside environment and does not have strong insulative properties. Discomfort from overcrowding and lack of adequate protection against

Figure 1:View of uninstalled Emergency Floor tiles

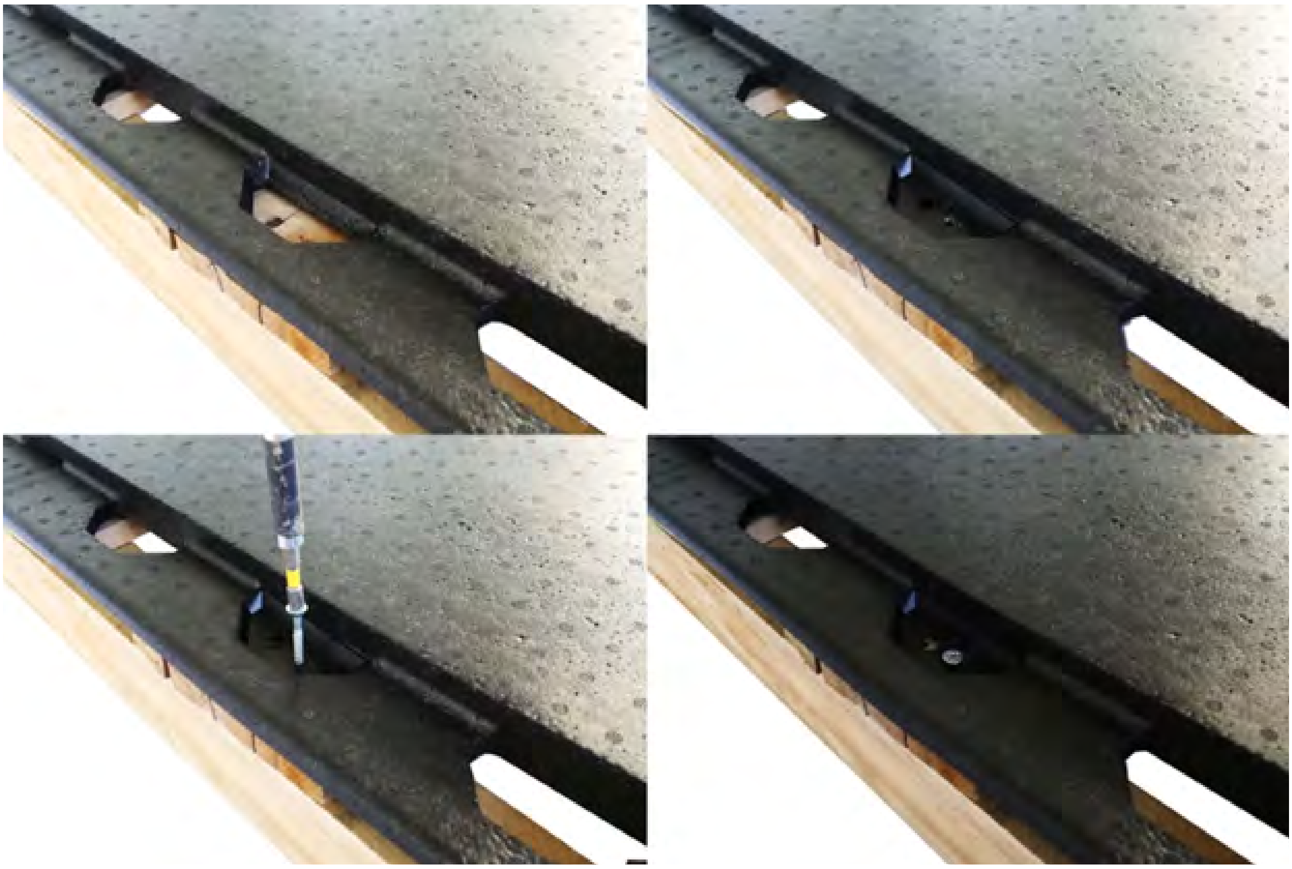

Figure 2: Installation of an Emergency Floor tile onto a wooden shipping pallet

external environments, which are commonly observed in temporary refugee settlements, undoubtedly have effect on an individual's ability to sleep well.

Whilst research has been conducted on optimal overall temporary shelter design, very little has focused specifically on shelter flooring (Ashmore et al., 2003). The goal of this study is to assess how installation of durable temporary flooring systems, like the Emergency Floor (EF), impacts sleep quality and duration, amongst displaced refugees. We hypothesise that installing durable flooring will improve sleep quality, increase sleep duration, and make a positive impact on participants living in tented refugee settlements.

1.1 Emergency Floor Details

The Emergency Floor (www.emergencyfloor.com) is a quickly deployable, lightweight, and inexpensive insulated flooring system made of expanded polypropylene. The purpose of EF is to protect temporary structures (such as refugee tents) from extreme temperatures, unwanted animals, and adverse climatic conditions such as excessive water or snow accumulation.

The EF is modular design consisting of individual tiles that can be arranged as desired and cut to fit with a common knife. Ten square meters (m^2) of Emergency Floor can be delivered and installed for approximately $200 USD. Figure 1shows an uninstalled view of the floor tiles.

Each individual EF tile weighs approximately 0.23 kg and covers 0.5 m^2. The lightweight, yet durable, material is easy to ship and can be quickly moved or relocated. The tiles are intuitive to install and can be installed without tools if necessary. In most settings, first-time users can install the floor in fewer than 10 minutes. The EF can either be installed directly on the ground or can utilise common foundation materials available in refugee settlements, including concrete slabs, sand bags, or wooden shipping pallets, as shown in Figure 2.

2 METHODS

The current study enrolled households from two tented refugee settlements in the Baalbek-Hermel Governorate of Lebanon. This Governorate is in the north-eastern portion of the country near the Syrian border and contains the highest percentage (48%) of refugees living in informal tented settlements (UNHCRb, 2017). These specific settlements were chosen based their proximity to the Syrian border, variance in topography (one was located in a flat field and the other on a hillside near a river), and

Figure 3 (top): A typical refugee shelter in the selected settlement before Emergency Floor installation

Figure 4 (bottom): The same shelter after Emergency Floor installation

total number of households contained. Funding availability allowed for EF installation in approximately 30 to 40 shelters.

Each of the 34 total households across the two settlements agreed to participate in the study and had an Emergency Floor installed in their shelter at no personal cost. A two-part survey was administered to each household by a bilingual trained volunteer in order to collect overall demographic and health data as well as data regarding sleep quality and duration.

The survey was adapted using input from local collaborators to better gauge specific concerns unique to Lebanese informal tented settlements. The survey was written in English and then translated into Arabic by a bilingual interpreter. After a separate interpreter confirmed the accuracy of the translation, the survey was printed and administered verbally in Arabic, the participants' native tongue.

Baseline data collection and Emergency Floor installation in all participating shelters occurred in October 2016. The follow-up survey was conducted in April 2017 to determine how EF installation impacted the participants. Seven households were unavailable for follow-up survey due to moving away from the settlement. The final sample was made up of 120 individuals from 27 households. No age restrictions were enforced.

To quantify how the EF affected the sleep of the individuals sampled, the April 2017 survey recorded participants' average hours of sleep per night and asked participants to rate their quality of sleep on a scale of

Table 1: Demographic information of October 2016 (N=150) and April 2017 (N=120). Note: number of years living in settlement was rounded to the nearest year.

Parameter	**October 2016**	**April 2017**
N (individuals)	150	120
Male N (%)	69 (46.0)	55 (45.8)
Age Median [Q1, Q3]	18.50 [6.3, 30.8]	20.00 [6.0, 31.3]
Age Category (years)		
0 - 4	26 (17.3)	21 (17.5)
5 - 14	41 (27.3)	31 (25.8)
15 - 24	26 (17.3)	18 (15.0)
25 - 39	36 (24.0)	33 (27.5)
40 - 49	8 (5.3)	6 (5.0)
50 or above	13 (8.7)	11 (9.2)
Number of Years Living in Settlement N (%)		
1 or less	7 (4.7)	7 (5.8)
2	44 (29.3)	28 (23.3)
3	33 (22.0)	24 (20.0)
4	16 (10.7)	16 (13.3)
5	45 (30.0)	41 (34.2)
Missing	5 (3.3)	4 (3.3)
N (Shelters)	34	27
Individuals per shelter N (%)		
2	6 (17.7)	4 (14.8)
3	5 (14.7)	4 (14.8)
4	9 (26.5)	8 (29.6)
5	6 (17.7)	6 (22.2)
6 or more	8 (23.5)	5 (18.5)

1 to 7 before and after EF installation. The head of the household, most commonly the matriarch, provided a detailed response to the question: "How does the Emergency Floor affect your sleep?" and provided responses for any subjects unable to respond independently (such as young children).

Paired two-sample Wilcoxon Rank-Sum tests, with a two-tailed significance level of 0.05, were used to assess differences in key outcome variables (sleep quality and duration) before and after EF installation. Figure 3 and Figure 4 show the inside of a shelter before and after EF installation respectively.

3 RESULTS

Basic demographic information of the October 2016 sample of 34 households, consisting of 150 total individuals, is shown in Table 1.

Table 1 shows that there were slightly more females than males at each surveyed time-point, and that a clear majority (95.3% at baseline and 94.1% at follow-up) of the subjects had been living in their shelter for two years or more and many shelters housed six (6) or more individuals (minimum of 2, maximum of 9). The sample consisted of many young individuals and had a mean age of 21.19 years, a median age of 18.5 years, and ranged from six (6) months old to 68 years old. The first and third quartiles, representing the boundaries of the middle 50% of the data, were 6.25 years and 30.75 years respectively.

Before EF installation, 32 households reported that the only flooring system in the tent was a plastic sheet, one reported that they had a synthetic mat along with the plastic sheet, and one indoor flooring material was unreported. Participants reported an average of 9.3 hours of sleep per night (Median [IQR]= 10 [9,10]) before EF installation. After EF installation participants reported an average of 10.26 hours of sleep per night (Median [IQR] = 10 [10,11]). Figure 5 shows the distribution of self-reported average hours of sleep per night before and after the installation of the EF.

Participants scored average sleep quality on a scale of 1 to 7, with 1 representing the lowest quality and 7 representing the highest quality. Participants reported an average sleep quality score of 3.14 (Median [Q1, Q3] = 3 [2,4]) before EF installation. After EF installation participants reported an average sleep quality score of 5.83 (Median [IQR] = 5 [5,6]). Figure 6 displays the difference in sleep quality before and after EF installation.

Since the same households were interviewed at the follow up survey, the before and after groups are not independent. Upon inspection, the distribution of sleep quality and duration were not normally distributed. Therefore, two-sided paired Wilcoxon rank-sum tests were used to assess differences before and after EF installation.

Results indicated that sleep duration significantly increased ($p_{Duration} < 0.001$) and sleep quality significantly improved ($p_{Quality} < 0.001$) after installation of the EF ($\alpha = 0.05$). Of the 27 heads of household

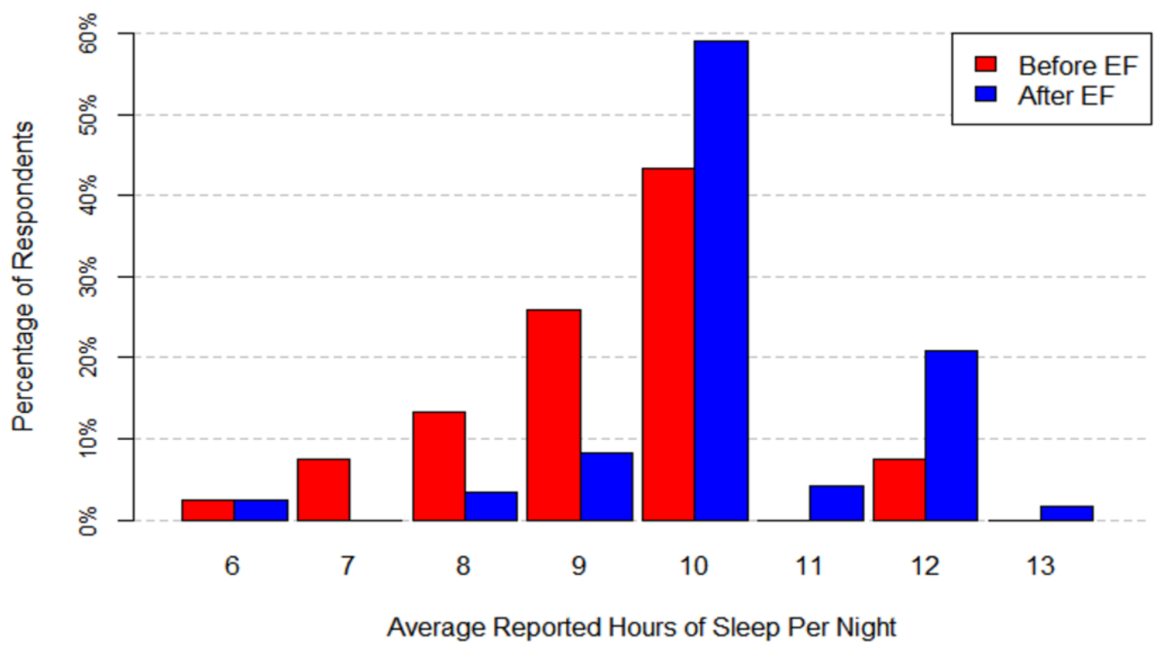

Figure 5: Self-reported average reported hours of sleep per night before (average = 9.3, median = 10, IQR = [9,10]) and after (average = 10.26, median = 10, IQR = [10,11]) EF installation

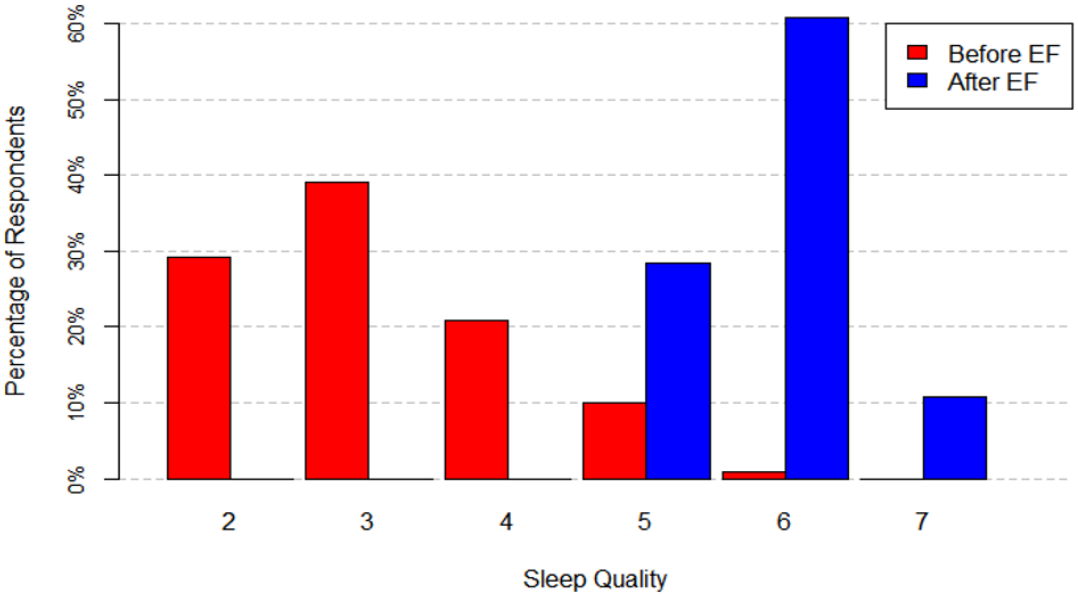

Figure 6: Self-reported sleep quality on a scale of 1 (lowest) to 7 (highest) before (average =3.14, median [Q1, Q3]= 3 [2, 4]) and after (average = 5.83, median [Q1, Q3] = 5 [5, 6]) EF installation

interviewed in the April 2017 follow-up survey, 26 (96.3%) provided a response to the question "How does the Emergency Floor affect your sleep?" which indicated that EF installation positively affected their sleep and 1 (3.7%) household decided to use the EF in the kitchen rather than sleeping area. Detailed reasons for why subjects' sleep improved included: more comfortable sleeping surface, warmer temperature inside the tent at night, easier to keep clean and dry, and feeling safer. Counts of these detailed responses are displayed in Table 2.

The temperature inside the shelter during sleeping hours depends on both outside environment and fuel consumption of the heater. Of the 27 households from which follow-up data were collected in the April 2017 survey, 13 (48.1%) reported using less fuel and 14 (51.9%) reported using the same amount of fuel after EF installation. No household reported using more fuel after EF installation. Subjects reported that the savings in fuel costs enabled them to spend more money on food, pay off debts, and buy medicine for children and elderly family members.

4 DISCUSSION

This research was completed to determine how installation of durable temporary flooring systems, like the Emergency Floor, could improve sleep quality and duration among displaced refugees. While the number of displaced people continues to rise, health and wellness for this population should be addressed from multiple sources.

The participants surveyed started without any durable or permanent flooring and instead relied on plastic sheets for a comfortable sleeping surface and protection from the outside environment. After EF installation, participants reported an increase in sleep quality as well as sleep duration, as well as positive responses to open ended questioning. These results suggest an overall increase in perceived wellness. The floor proved to be durable and only minimal damage was reported.

The current study has several notable strengths and contributions to refugee health literature. First, this is the first study, to our knowledge, which focuses on potential benefits of durable flooring installation in tented

Table 2: Detailed reasons for how EF installation affected sleep in each household

Parameter	N	%
More Comfortable	15	55.6
Cleaner	6	22.2
Warmer at Night	4	14.8
Safer	1	3.7

communities. Tented walls and ceilings are obvious, integral parts of the overall shelter, but it should be remembered that inhabitants spend most of their time in direct contact with the shelter's floor. Additionally, this study enrolled a sample that exemplifies the overall target population. Instead of relying on testing in a controlled environment with subjects who would not use the floor long-term, this study collected data from subjects likely to continue using the floor in the future. Also, the study participants assessed the floor over the course of approximately six months rather than only a few days. This extended exposure to the floor enabled the study respondents to provide a more robust opinion on how the floor affected their sleep quality and duration. Finally, conducting the survey in the participant's native language protected against information being lost in translation.

A few limitations of the study were also apparent. The most obvious limitation was the potentially unreliable nature of self-reported sleep data. However, in the absence of availability of objective measurement or confirming results with a bed-partner, self-reporting of sleep outcomes remains the most practical method of measuring sleep quality and duration (Tamakoshi and Ohno, 2004; Sharwood et al., 2012). Furthermore, since this study did not restrict participants based on age, young children may have relied on their parents to help answer questions. This could lead to high correlation of data within a household. Fatigue of the survey administrator was another area of concern, as only one community health worker administered the survey. However, no obvious mistakes were observed in the data. Additionally, the survey time frame was completed during the winter months and does not capture the complete climatic effects on camp life experienced throughout the year. However, since winter tends to cause the harshest environmental conditions for refugees, the fact that the floor performed well through the winter months suggests that it is also beneficial in other seasons.

5 CONCLUSION

Overall, this study effectively demonstrated that sleep quality and duration among refugees significantly improved after installation of a durable, temporary flooring system. Additionally, the subjects also reported positive psychological outcomes (as reported in Table 2) including feeling safer and more comfortable in their home. These results suggest that installation of durable flooring should be considered when constructing temporary shelters. Future research could also investigate other potential benefits of floor installation such as assessing disease and infection rates between households with and without floors, and a thorough assessment of how floor installation impacts fuel consumption. Incorporating randomised assignment of households to various flooring comparable systems could also be considered to assess performance across flooring type. Furthermore, installation of durable transportable flooring, such as the Emergency Floor, could be adapted for use in other temporary structures, such as forward surgical hospitals or disaster relief shelters.

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