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

Jerrel Gilliam
The Pennsylvania State University, United States

Khanjan Mehta
Lehigh University, United States
krm716@lehigh.edu

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

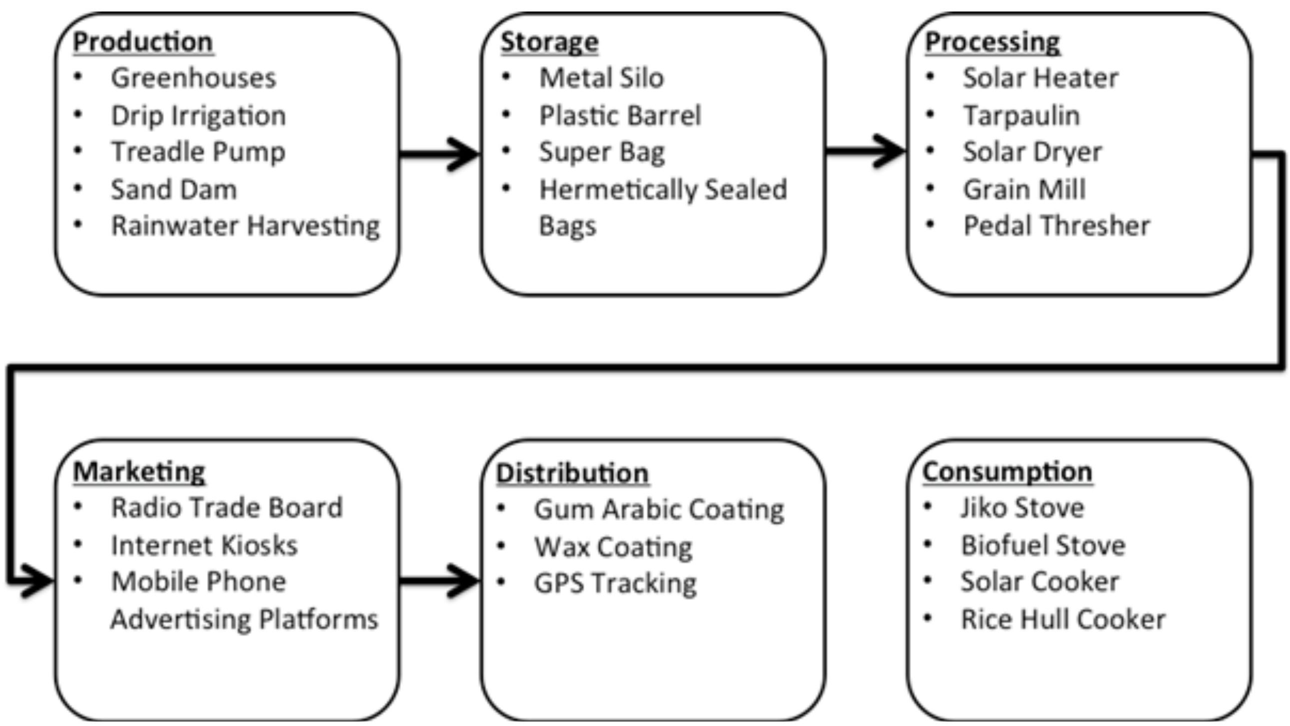

Figure 1: Simplified Food Value Chain with examples of relevant technologies

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

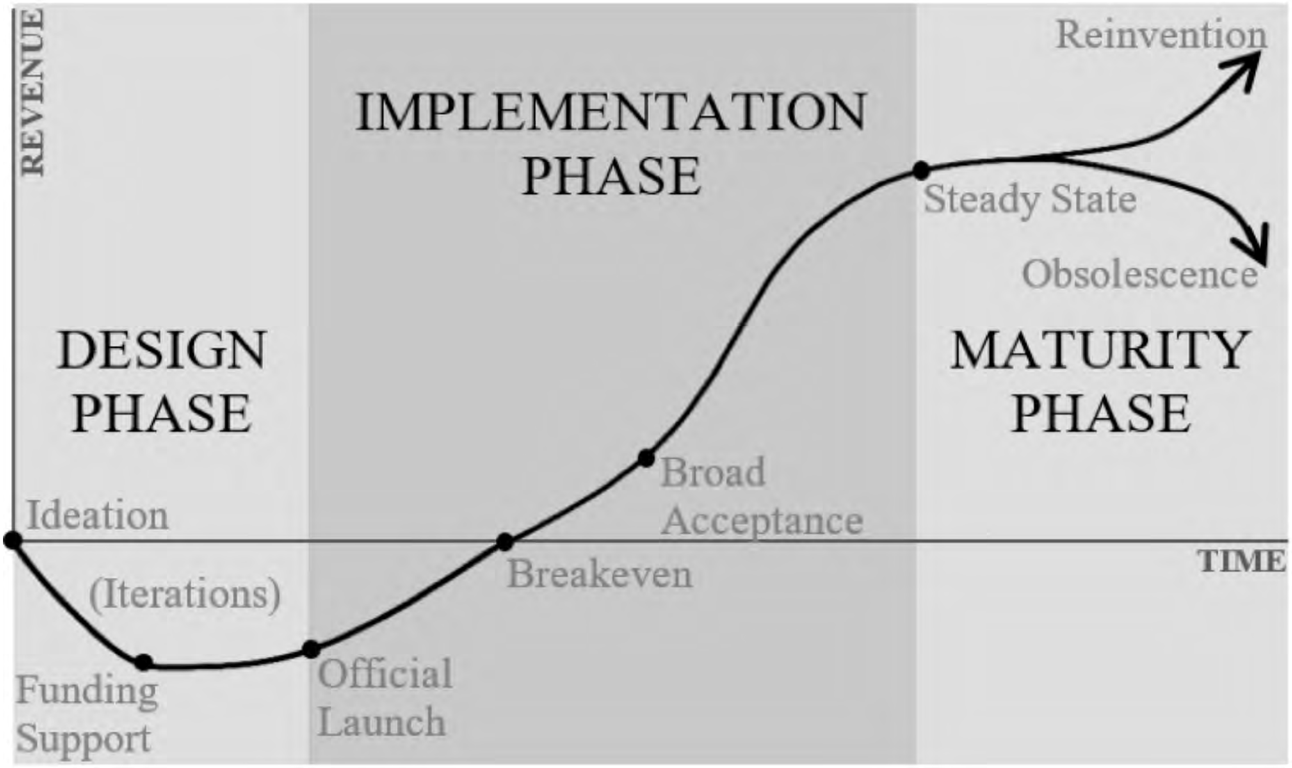

Figure 2: Venture Lifecycle – Design, Implementation, and Maturity Phases. Adapted in part from Norman, 1998. (Maley, Perez, and Mehta, 2013.)

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

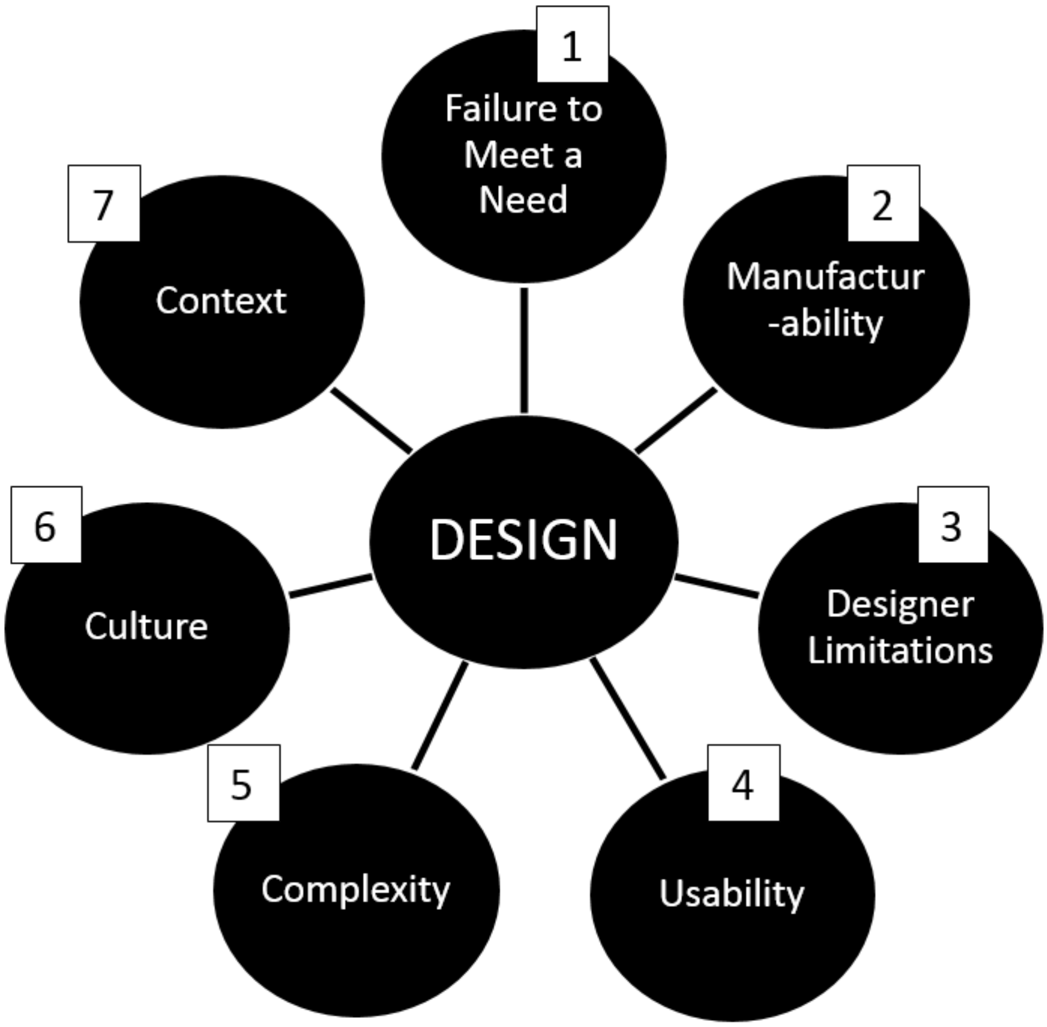

Figure 3: Challenges encountered by agricultural technology ventures during the design phase

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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