Computing within Limits and ICTD

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ABSTRACT

Computing research today is fixated on high performance and large scale, but computing can be tremendously powerful even at low power and small scale. In this article we present a perspective on promising directions for research on computing within limits, where concerns about limits overshadow performance and scale. Despite coming from different motivations, computing within limits has very similar considerations as Information Communication Technology for Development (ICTD). We discuss where the two research areas intersect and where they may diverge. We draw parallels between computing within limits and ICTD in terms of technical constraints, designing for context, and goals. We hope to help stimulate computing within limits with ideas from ICTD and highlight research synergies.

1. INTRODUCTION

A modern smartphone gives anyone with an Internet connection access to billions of people around the world and petabytes of information in the palm of their hand. This is a miraculous technological achievement, and yet, computing with its potential to dramatically improve our lives rarely realizes this possibility. This unfortunate situation is the result of our recent innovations largely focusing on advancing consumerism. In a world with infinite resources, infinite growth could be sustainable, and plausibly good. However, we wonder whether it makes sense to continue in this direction when resources are dwindling and the marginal benefits are increasingly marginal.

Information Communication Technology for Development (ICTD) is one of the few sub-fields within computer science that attaches a moral value system to its agenda. ICTD attempts to confront some of the extant socio-economic inequities in developing regions through the design and deployment of Information Communication Technologies (ICTs). The domain that ICTD researchers concern themselves with is defined by the socio-economic condition of poverty, which generally corresponds to some combination of low infrastructure, meager education, deficient healthcare, unreliable food supply, weak or corrupt government, etc. While it is unclear whether any or all of these conditions will be applicable to computing with limits, it is certainly true that limits on computation are imposed by these conditions. Therefore, ICTD can offer existing real-world examples of situations where limits on computing are forcibly enforced.

Given the overlap between computing within limits and ICTD, our goal in this paper is to borrow ideas incubated from within ICTD to frame the research agenda for computing within limits. In the remainder of this paper, we describe the relevant issues in ICTD, highlight the overlapping concerns with computing within limits, and distill research directions for computing within limits.

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2. ICTD

ICTD first began in the 1940's when televisions were thought to have the potential for bringing education into the home. More recently, the introduction of networked computers in urban telecenters, high mobile phone penetration in developing countries, and large-scale data analytics have attracted computer scientists to ICTD. ICTD is highly interdisciplinary, involving computer scientists of many stripes and researchers from anthropology, sociology, economics, public policy, and design. Also, unlike purely academic fields, ICTD also includes practitioners and interventionists from government and NGOs who want to use ICTs to improve socio-economic outcomes. Here, we focus mainly on outlining computing-centric contributions to ICTD that are relevant to computing with limits.[1]

2.1 Constraints

Even before dealing with individual constraints, simply measuring and understanding the technical challenges can often be a challenge in itself due to the lack of measurement infrastructure [9, 24, 19]. Assuming that a problem has been successfully characterized, existing approaches to ICTD typically emphasize interventions that are designed to be contextually *appropriate*. From a technical standpoint, appropriate typically implies some combination of: low cost, low infrastructure, and high usability, while also targeting one or several development metrics (e.g. education, health, agriculture). This is difficult for at least three fundamental reasons. First, designing such technology interventions is hard; each design requirement by itself is challenging to achieve individually and they are extremely difficult to achieve in concert. Unfortunately many of the technical challenges are interrelated and it is often not possible to isolate and address them independently. Second, interventions (and 'novel' ICTs in

[1] For a more detailed survey of ICTD [20, 21, 36, 50, 17].

particular) have high costs in terms of manufacturing, training, infrastructure support (e.g. Internet access for a mobile application), and maintenance. Since even the technology intervention itself is so challenging to design, implement, test, deploy, and evaluate, very little consideration (and design flexibility) remains to be given to how the intervention will sustain itself. Third, contexts are often different enough to often require different solutions, but ICT solutions are often brittle and highly optimized. As a result of these three factors, very few bottom of the pyramid interventions succeed in the initial pilot phase; even when pilots do succeed, they fail to sustain themselves and scale.

2.1.1 Low Cost

Low cost ICTD typically emphasizes low equipment cost, but could also include low maintenance cost. Low equipment cost ICTD focuses on designing cheaper computing hardware [38, 25, 22, 1], replicating existing useful applications on top of cheaper computing platforms e.g. mobile phones [35, 28, 5, 45], or creating novel applications on cheap devices [35, 19, 5, 6]. Low maintenance cost typically implies that it is within the means of the organization sponsoring the intervention or the users themselves to keep the system running. Technical innovations here include low-power equipment or cheap communications such as voice or SMS services that require very few or short messages [53, 6].

2.1.2 Low Infrastructure

ICTD solutions that emphasize low (or unreliable) infrastructure requirements tend toward designing systems that function despite low power or low connectivity [4, 43, 7, 47]. Solutions that deal with low infrastructure typically emphasize graceful degradation or continued service, but some efforts deal with the deployability of infrastructure itself [1]. Sometimes the low cost solution also addresses low infrastructure problems, e.g. solar may be cheaper, more reliable, and more accessible than grid power [43]. There are other interesting examples where high cost actually simulates low infrastructure (e.g. expensive Internet causes users to self-impose on-demand network connectivity). Intermittent web systems cope with both expensive and unreliable connectivity without much distinction [7, 47, 37].

Crisis Response - Crisis response is tangentially related to ICTD. Crisis response solutions are bifurcated into rapidly deployable low requirement infrastructures or real-time inferences based on large-scale data [46]. In contrast to ICTD, crisis response focuses on the immediate humanitarian crisis rather than sustainability concerns. In the context of limits, it could be interesting to consider crisis response systems that are easily deployable, arbitrarily extensible, externally compatible, and self-sustainable.

2.1.3 Usability

In many developing regions, users have very little experience with ICTs and less education than in rich countries. Research efforts to address these challenges include pictorial interfaces [31], speech-based interfaces [52, 42], and other simplified interfaces or interaction designs [30, 11, 27]. Other works seek to preserve existing practices to leverage affordances of traditional technologies such as pen and pencil [8, 13, 51] and bring technology into workflows through less disruptive means. Low education may be less immediate of a problem in computing with limits depending on the kinds of scenarios considered, but certainly limitations imposed by user capabilities (e.g. attention) could be one class of limits.

2.2 Interventions

The general goal of ICTD is to introduce technology to facilitate improvement in a development metric [17, 12]. However, when introducing an intervention there are many considerations beyond the purely technical.

2.2.1 Context

As technologists, we often presume that technology is the solution to problems when often it is not. Toyama observed that technology is just a tool that can be used to amplify human intent [49]. While certain technologies can be targeted at amplifying only positive intents, interjecting a technology without consideration of the context is likely doomed to fail. Creating a cheap, infrastructureless, and easy to use technology is not sufficient to guarantee positive outcomes. Furthermore, it has been demonstrated that satisfying these technical requirements is sometimes not even necessary for adoption [44].

What then is it about context and what makes a technology appropriate for that context? We use 'context' here as an umbrella term that encompasses all of the not-necessarily-technical milieu surrounding a user, which may include social, political, economic, and psychological factors. We refer the reader to [20, 3] for more details. In terms of the non-technical contributions to ICTD, most have to do with the investigation and understanding of users and their concerns. Many researchers in ICTD have written about this [34, 2, 33, 40, 15], but the common theme is that non-technical considerations play a critical part in the success of an intervention [29]. Also, beyond deployment, success means having users adopt the technology, the technology actually doing 'good', and eventually sustaining itself.

Given that the users in certain computing within limits scenarios do not exist yet, we do not have a clear target user and context to work with. Tomlinson et al. make the observation that the designing for 'collapse informatics' is essentially a cross-cultural design problem of "designers in the present attempting to design systems for their future selves and families in a time of scarcity ... [and] it is impossible for a researcher or designer to engage with the anticipated users and seek to understand their needs and ways of viewing the world in which they live, or engage in action research" [48].

To ameliorate this problem we borrow a (philosophical) notion from "Ethics for a Broken Future World" [32], that people in the future, who are impoverished because of environmental choices we make today, have the same relation to us as people today in other countries who are impoverished for other reasons (e.g. people in developing countries).[2] In other words, since many challenges in ICTD involve limits and cross-cultural design, ICTD may naturally be considered as one practicable realm of computing within limits.

[2]Mulgan uses this idea to advance philosophical arguments, but we use it literally.

The Bottom of the Pyramid - In ICTD, efforts to design for the 'bottom of the pyramid' (the poorest of the poor) is difficult because these users and contexts have so many constraints. Successes in ICTD have largely been in the form of technologies that improve the capabilities of organizations that then help the poor directly. In the case of economic collapse it may be an 'easier' design problem depending on where in the timeline we choose to operate. E.g. People may be familiar with technology and be well-educated despite rapid impoverishment.

2.2.2 *Adoption*

Even if we develop a technology that is good enough to solve a problem outright (e.g. vaccinations), there are deployment and adoption challenges. Beyond the socio-economic situation, the core problems in development often have to do with people and their choices. Specifically, people have aspirational, motivational, and behavioral barriers that need to be addressed. For example, it is incredibly difficult to convince someone with very few resources to make changes in practices that involve even small amounts of risk (since the poor are extremely sensitive to risk). Another challenge is that people's immediate goals are often not aligned with development goals. Providing Internet access to schools only to have most of the bandwidth being used for entertainment rather than education is one common example. Distributing bednets to prevent malaria from mosquitoes and having the bednets used for fishing is another known outcome [16].

2.2.3 *Sustainability and Scale*

Many ICTD projects involve deployments, during which users adhere to the intervention. However, projects that lose or finish their funding may have no sustainability plan, exit strategy, or built-in self-obsolescence. After the project ends and the organization departs, the situation becomes just as bad as it was prior to the intervention [26, 14]. Part of the challenge is due to the multifarious constraints in ICTD that result in a lack of remaining design space for sustainability. In other words, it is so difficult to build something that is cheap and functional that sustainability becomes an afterthought. Further research is required to understand how to design technologies that gracefully degrade and also interventions that gradually make themselves obsolete.

Reuse - Bricolage, or the construction or creation from a diverse range of available things, is a relevant concept for constrained environments. In India, the local term for bricolage is "Jugaad", and there are many documented examples where industrious individuals solve problems through Jugaad [41]. Bricolage is commonly practiced informally in developing regions and is a yet under-explored design idea that merits consideration [23]. As a contributor to the definition of resilience, bricolage is a useful model for reuse and compellingly motivates modular systems design. Designing with bricolage as a goal could be useful for maintenance in the face of equipment failure, infrastructure failure, and knowledge failures.

3. COMPUTING WITHIN LIMITS

Before defining a research agenda of computing within limits, we must discuss the failure model we expect, end-goals or desired outcomes, and metrics for success. First, thus far we have used ICTD as a proxy for the conditions of eventual limits, but there is an indeterminable path of failure between the present and a future situation. What, therefore, is the failure model we are expecting or devoting our efforts toward? E.g. Peak oil, climate change, Moore's law, etc. Second, given the failure model, what are the goals of computation within limits? Do we wish to subsist in low-tech world forever or do we seek to recover from catastrophic failure and resume our descent toward the next catastrophe? Is there a middle ground? Third, what are our metrics for success? Unlike ICTD, where metrics are defined and experimental outputs are measured for evaluation, many failure models and design goals cannot be tested until after the fact. In this paper we briefly outline one failure model we think is likely and defer the discussion of other models and statement of values for future work. We conservatively assume that the goal is to design and deploy resilient computing technologies. Thus, simulated failures or deployments in failing regions may be sufficient evaluations.

3.1 Failure Model

Failure models are outside of the scope of this paper, but defining failure models, goals, and metrics for computation within limits is critical to crystallizing a definitive research agenda.[3]

If we assume that degrowth via catabolic collapse [18] will be the path toward eventual computing within limits rather than immediate catastrophic collapse, then we may consider focusing on technologies that bridge developing region conditions to first-world systems. E.g. intermittent aware/tolerant systems. Education or financial systems that can work despite heterogeneous infrastructures. In the first stages of collapse, the general conditions may be similar to Greece today: high unemployment and austerity measures with increasing severity. It is unclear what the technological solution to mitigating this problem could possibly be as the problem is largely economic and political. Should people spend less and wait for the economy to eventually wind down or should the government or European Union infuse the economy with bailouts and loans?

Without some kind of intercession, maintenance of public infrastructure and services may deteriorate and finally fail until, over a long period of time, the country devolves into something akin to a developing country of the present day. Assuming this failure model, one could build technologies that slow down this process or build technologies that continue function afterwards. Research on computing within limits appears to encompass both, but some calculus must be performed to ascertain where contributions could be made. At the degenerate endpoint of this trajectory, conditions would be similar in many ways to those of today's poorest developing countries.

3.2 Design for Resilience

Sustainability[4] and resilience are not areas where ICTD

[3]We refer readers interested in failure models and their potential consequences to [48, 39], which contain more detailed overviews.

[4]Here we use the term sustainability to refer to ICTD in-

has traditionally succeeded. Given the current connotation of the term, 'sustainability' (i.e. green computing), it is unclear whether it should be promoted to a first-order goal of computing within limits. The focus of computing within limits is not so much that we should design systems to conserve energy use, but rather that the results of approaching fundamental physical limits imposes several constraints, of which, one is energy use. As in ICTD, constraints within which computation should be able to function include, but are not limited to: electricity, networking, transportation, replacement, and repair.

Assuming that the goal of computing within limits is resilience, the design opportunities as compared to ICTD are threefold. First, we are currently operating at a point in time prior to collapse so we have comparatively vast resources and a head start. Second, collapse will not mean the immediate reduction of human and infrastructural capacity, which, as we have noted is a central problem in ICTD. Third, the contexts of developed civilizations are substantially more homogenized than developing regions due to westernization. It may be premature to firmly establish the principles of computing within limits, but from the technology standpoint the design goals that intersect between ICTD and the expected conditions of computing within limits are the following:

1. **Simplicity.** Limits computing should emphasize technologies that are simple. While user interfaces should be simple to satisfy usability requirements, the underlying technology needs to be simple to facilitate maintenance and independence from infrastructure.

2. **Infrastructure Independence.** Reliable electricity, network connectivity, transportation, and even government may be problems in limits situations. During initial decline these are likely to be soft limits, but may eventually deteriorate to the same levels as developing regions of today. Systems should be designed to gracefully degrade when infrastructures decay.

3. **Modularity.** With heavy industry, large-scale manufacturing, and global shipping becoming limited, new technologies and replacement components will be less likely over time. Technology should be designed that is largely interoperable and modular so that components may be easily interchanged and replaced locally.

These design goals generally echo the doctrines proscribed by Raghavan and Ma in the context of networking design in the 'long emergency' (cf. [39]).

3.3 Context

Note that context, cost, and usability were not listed as requirements to computing within limits, but context is a critical consideration. Context is defined broadly (as it is in ICTD) by the socio-economic, geo-political, and physical environment of the target site. Context, therefore, dictates cost and usability constraints. While it is possible that challenges such as language localization exist in limits contexts, we posit that given the homogenization of developed countries limits contexts are initially similar (relative to the diversity of development contexts).

The notion of cost (transportation, energy, and labor) is folded into the constraints imposed by infrastructure and modularity given a particular limits context since those costs will drastically increase. Similarly, usability is implicitly considered as a part of simplicity, but usability itself is also less of a central concern in initial failure contexts due to pre-existing familiarity with technology and other individual capabilities.

3.4 Adoption

As with ICTD, the crux of the problem after technology design has to do with people themselves. Assuming the failure model of slow gradual or catabolic collapse, a more limits-aware technology may not be adopted solely because it is slightly less performant or more expensive. Since the problem is such an intangible tragedy of the commons with yet un-experienced future costs, people may not care enough to adopt solutions. People may use limits-based solutions if their mental models change or it becomes untenable to maintain old models because limits were somehow imposed.

In ICTD contexts are different and often require different solutions to facilitate adoption [2, 10]. As with ICTD, adoption will likely face challenges, but unlike ICTD the barriers are lower since we currently have substantially more material wealth than the average poor person in a developing country. However, this present wealth is counterbalanced by correspondingly higher levels of consumerism and performance (or quality) expectations. As visible evidence of our unsustainable growth accumulates, people may change their behavior and adopt more sensible technology, but by then our available material resources will be lower than today. As with ICTD, awareness campaigns, psychological nudges, and goal aligned interventions are all interesting avenues to consider for encouraging people to embrace change.

4. CONCLUSION

In this paper we explored computing within limits from the perspective of the last decade of work in ICTD. We find many similar constraints between computing within limits and ICTD, but ultimately slightly different emphasis. While understanding context, users, and cost are still concerns in limits computing, the focus of designing for limits shift toward resilience and possibly sustainability. We find that the main requirements for achieving resilience include: simplicity, infrastructure independence, and modularity. While these ideas have been explored in ICTD literature, the design space across these axes has been largely unexplored in ICTD due to substantial contextual constraints imposed by cost and usability. Like ICTD, context, cost, and usability are all likely to be important considerations for designing for computing within limits and central determinants for adoption and sustainability.

5. REFERENCES

[1] Anand, A., Pejovic, V., Belding, E. M., and Johnson, D. L. Villagecell: cost effective cellular

tervention sustainability rather than the sustainable computing sense of low or green power. Elsewhere, we use the term more broadly to mean the general notion of a system sustaining itself in a context.

connectivity in rural areas. In *Proceedings of the Fifth International Conference on Information and Communication Technologies and Development* (2012), ACM, pp. 180–189.

[2] Bajpai, K., Larson, J. B., and Mehta, K. Like a hustler: aligning intervention design with informal labor practices. In *Proceedings of the Sixth International Conference on Information and Communication Technologies and Development: Full Papers-Volume 1* (2013), ACM, pp. 177–184.

[3] Brewer, E., Demmer, M., Du, B., Ho, M., Kam, M., Nedevschi, S., Pal, J., Patra, R., Surana, S., and Fall, K. The case for technology in developing regions. *Computer 38*, 6 (2005), 25–38.

[4] Chandan, V., Jain, M., Khadilkar, H., Charbiwala, Z., Jain, A., Ghai, S., Kunnath, R., and Seetharam, D. Urjar: A lighting solution using discarded laptop batteries. In *Proceedings of the Fifth ACM Symposium on Computing for Development* (2014), ACM, pp. 21–30.

[5] Chaudhri, R., Brunette, W., Goel, M., Sodt, R., VanOrden, J., Falcone, M., and Borriello, G. Open data kit sensors: mobile data collection with wired and wireless sensors. In *Proceedings of the 2nd ACM Symposium on Computing for Development* (2012), ACM, p. 9.

[6] Chen, J., Subramanian, L., and Brewer, E. Sms-based web search for low-end mobile devices. In *Proceedings of the sixteenth annual international conference on Mobile computing and networking* (2010), ACM, pp. 125–136.

[7] Chen, J., Subramanian, L., and Li, J. Ruralcafe: web search in the rural developing world. In *Proceedings of the 18th international conference on World wide web* (2009), ACM, pp. 411–420.

[8] Chen, K., Kannan, A., Yano, Y., Hellerstein, J. M., and Parikh, T. S. Shreddr: pipelined paper digitization for low-resource organizations. In *Proceedings of the 2nd ACM Symposium on Computing for Development* (2012), ACM, p. 3.

[9] Chetty, M., Sundaresan, S., Muckaden, S., Feamster, N., and Calandro, E. Measuring broadband performance in south africa. In *Proceedings of the 4th Annual Symposium on Computing for Development* (2013), ACM, p. 1.

[10] Corrigan-Gibbs, H., and Chen, J. Flashpatch: spreading software updates over flash drives in under-connected regions. In *Proceedings of the Fifth ACM Symposium on Computing for Development* (2014), ACM, pp. 1–10.

[11] Cross, A., Cutrell, E., and Thies, W. Low-cost audience polling using computer vision. In *Proceedings of the 25th annual ACM symposium on User interface software and technology* (2012), ACM, pp. 45–54.

[12] Dearden, A. See no evil?: ethics in an interventionist ictd. In *Proceedings of the Fifth International Conference on Information and Communication Technologies and Development* (2012), ACM, pp. 46–55.

[13] Dell, N., Breit, N., Chaluco, T., Crawford, J., and Borriello, G. Digitizing paper forms with mobile imaging technologies. In *Proceedings of the 2nd ACM Symposium on Computing for Development* (2012), ACM, p. 2.

[14] Dodson, L. L., Sterling, S., and Bennett, J. K. Considering failure: eight years of itid research. In *Proceedings of the Fifth International Conference on Information and Communication Technologies and Development* (2012), ACM, pp. 56–64.

[15] Frias-Martinez, V., and Virseda, J. On the relationship between socio-economic factors and cell phone usage. In *Proceedings of the Fifth International Conference on Information and Communication Technologies and Development* (2012), ACM, pp. 76–84.

[16] Gettleman, J. Meant to keep malaria out, mosquito nets are used to haul fish in. http://www.nytimes.com/2015/01/25/world/africa/mosquito-nets-for-malaria-spawn-new-epidemic-overfishing.html, 2015.

[17] Gomez, R., Baron, L. F., and Fiore-Silfvast, B. The changing field of ictd: content analysis of research published in selected journals and conferences, 2000–2010. In *Proceedings of the Fifth International Conference on Information and Communication Technologies and Development* (2012), ACM, pp. 65–74.

[18] Greer, J. M. *How civilizations fall: A theory of catabolic collapse*. Citeseer, 2005.

[19] Hartung, C., Lerer, A., Anokwa, Y., Tseng, C., Brunette, W., and Borriello, G. Open data kit: Tools to build information services for developing regions. In *Proceedings of the 4th ACM/IEEE International Conference on Information and Communication Technologies and Development* (2010), ACM, p. 18.

[20] Heeks, R. Information systems and developing countries: Failure, success, and local improvisations. *The Information Society 18*, 2 (2002), 101–112.

[21] Heeks, R. Ict4d 2.0: The next phase of applying ict for international development. *Computer 41*, 6 (2008), 26–33.

[22] Heeks, R., and Robinson, A. Ultra-low-cost computing and developing countries. *Communications of the ACM 56*, 8 (2013), 22–24.

[23] Jackson, S. J., Ahmed, S. I., and Rifat, M. R. Learning, innovation, and sustainability among mobile phone repairers in dhaka, bangladesh. In *Proceedings of the 2014 conference on Designing interactive systems* (2014), ACM, pp. 905–914.

[24] Johnson, D. L., Belding, E. M., Almeroth, K., and van Stam, G. Internet usage and performance analysis of a rural wireless network in macha, zambia. In *Proceedings of the 4th ACM Workshop on Networked Systems for Developing Regions* (2010), ACM, p. 7.

[25] Kraemer, K. L., Dedrick, J., and Sharma, P. One laptop per child: vision vs. reality. *Communications of the ACM 52*, 6 (2009), 66–73.

[26] Kuriyan, R., Toyama, K., and Ray, I. Integrating social development and financial sustainability: The challenges of rural computer kiosks in kerala. In *Information and Communication Technologies and Development, 2006. ICTD'06. International Conference on* (2006), IEEE, pp. 121–130.

[27] Li, L. D., and Chen, J. Trotro: Web browsing and user interfaces in rural ghana. In *Proceedings of the Sixth International Conference on Information and Communication Technologies and Development: Full Papers-Volume 1* (2013), ACM, pp. 185–194.

[28] Librero, F., Ramos, A. J., Ranga, A. I., Triñona, J., and Lambert, D. Uses of the cell phone for education in the philippines and mongolia. *Distance Education 28*, 2 (2007), 231–244.

[29] Luk, R., Zaharia, M., Ho, M., Levine, B., and Aoki, P. M. Ictd for healthcare in ghana: two parallel case studies. In *Information and Communication*

Technologies and Development (ICTD), 2009 International Conference on (2009), IEEE, pp. 118–128.

[30] Medhi, I., Patnaik, S., Brunskill, E., Gautama, S., Thies, W., and Toyama, K. Designing mobile interfaces for novice and low-literacy users. *ACM Transactions on Computer-Human Interaction (TOCHI) 18*, 1 (2011), 2.

[31] Medhi, I., Sagar, A., and Toyama, K. Text-free user interfaces for illiterate and semi-literate users. In *Information and Communication Technologies and Development, 2006. ICTD'06. International Conference on* (2006), IEEE, pp. 72–82.

[32] Mulgan, T. *Ethics for Broken World: Imagining Philosophy After Catastrophe.* McGill-Queen's Press-MQUP, 2011.

[33] Natarajan, M., and Parikh, T. Understanding barriers to information access and disclosure for hiv+ women. In *Proceedings of the Sixth International Conference on Information and Communication Technologies and Development: Full Papers-Volume 1* (2013), ACM, pp. 143–152.

[34] Pal, J., Ammari, T., Mahalingam, R., Alfaro, A. M. H., and Lakshmanan, M. Marginality, aspiration and accessibility in ictd. In *Proceedings of the Sixth International Conference on Information and Communication Technologies and Development: Full Papers-Volume 1* (2013), ACM, pp. 68–78.

[35] Parikh, T. S., Javid, P., Ghosh, K., Toyama, K., et al. Mobile phones and paper documents: evaluating a new approach for capturing microfinance data in rural india. In *Proceedings of the SIGCHI conference on Human Factors in computing systems* (2006), ACM, pp. 551–560.

[36] Patra, R., Pal, J., and Nedevschi, S. Ictd state of the union: Where have we reached and where are we headed. In *Information and Communication Technologies and Development (ICTD), 2009 International Conference on* (2009), IEEE, pp. 357–366.

[37] Pentland, A., Fletcher, R., and Hasson, A. Daknet: Rethinking connectivity in developing nations. *Computer 37*, 1 (2004), 78–83.

[38] per Child, O. L. One laptop per child, 2009.

[39] Raghavan, B., and Ma, J. Networking in the long emergency. In *Proceedings of the 2nd ACM SIGCOMM workshop on Green networking* (2011), ACM, pp. 37–42.

[40] Rangaswamy, N., and Cutrell, E. Anthropology, development and icts: slums, youth and the mobile internet in urban india. In *Proceedings of the Fifth International Conference on Information and Communication Technologies and Development* (2012), ACM, pp. 85–93.

[41] Rangaswamy, N., and Densmore, M. Understanding jugaad: Ictd and the tensions of appropriation, innovation and utility. In *Proceedings of the Sixth International Conference on Information and Communications Technologies and Development: Notes-Volume 2* (2013), ACM, pp. 120–123.

[42] Raza, A. A., Pervaiz, M., Milo, C., Razaq, S., Alster, G., Sherwani, J., Saif, U., and Rosenfeld, R. Viral entertainment as a vehicle for disseminating speech-based services to low-literate users. In *Proceedings of the Fifth International Conference on Information and Communication Technologies and Development* (2012), ACM, pp. 350–359.

[43] Rey-Moreno, C., Roro, Z., Tucker, W. D., and Siya, M. J. Community-based solar power revenue alternative to improve sustainability of a rural wireless mesh network. In *Proceedings of the Sixth International Conference on Information and Communications Technologies and Development: Notes-Volume 2* (2013), ACM, pp. 132–135.

[44] Sambasivan, N., and Smyth, T. The human infrastructure of ictd. In *Proceedings of the 4th ACM/IEEE International Conference on Information and Communication Technologies and Development* (2010), ACM, p. 40.

[45] Smith, Z. J., Chu, K., Espenson, A. R., Rahimzadeh, M., Gryshuk, A., Molinaro, M., Dwyre, D. M., Lane, S., Matthews, D., and Wachsmann-Hogiu, S. Cell-phone-based platform for biomedical device development and education applications. *PLoS One 6*, 3 (2011), e17150.

[46] Starbird, K., and Palen, L. Voluntweeters: Self-organizing by digital volunteers in times of crisis. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2011), ACM, pp. 1071–1080.

[47] Thies, W., Prevost, J., Mahtab, T., Cuevas, G., Shakhshir, S., Artola, A., Vo, B., Litvak, Y., Chan, S., Henderson, S., et al. Searching the world wide web in low-connectivity communities. In *Proceedings of WWW* (2002), vol. 2.

[48] Tomlinson, B., Silberman, M., Patterson, D., Pan, Y., and Blevis, E. Collapse informatics: augmenting the sustainability & ict4d discourse in hci. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (2012), ACM, pp. 655–664.

[49] Toyama, K. Technology as amplifier in international development. In *Proceedings of the 2011 iConference* (2011), ACM, pp. 75–82.

[50] Toyama, K., and Dias, M. B. Information and communication technologies for development. *IEEE Computer 41*, 6 (2008), 22–25.

[51] Underwood, H., Sterling, S., and Bennett, J. K. The design and implementation of the partopen maternal health monitoring system. In *Proceedings of the 3rd ACM Symposium on Computing for Development* (2013), ACM, p. 8.

[52] Vashistha, A., and Thies, W. Ivr junction: Building scalable and distributed voice forums in the developing world. In *6th USENIX/ACM Workshop on Networked Systems for Developing Regions* (2012).

[53] Zurovac, D., Talisuna, A. O., and Snow, R. W. Mobile phone text messaging: tool for malaria control in africa. *PLoS medicine 9*, 2 (2012), e1001176.