The Human Infrastructure of ICTD

Nithya Sambasivan and Thomas Smyth

***Abstract*—We argue for the importance of understanding the human infrastructure in ICTD projects. We do this through two field studies in low-income communities of Bangalore, India—on technology usage in urban slums and mobile media sharing on a wider scale. We offer ICTD researchers and practitioners an analytical lens to understand the shared social norms and practices, flows of information and materials, and creative processes that underlie existing information and communication access. We then provide a discussion of the systemic processes (usage, maintenance, and diffusion) and properties that constitute a human infrastructure. We end with opportunistic areas for ICT4D and human infrastructures. Through such a lens, we offer ICTD designers and researchers ways of understanding use and everyday practice to respond to developmental challenges through technologies.**

***Index Terms*—Infrastructures, India, design, HCI4D**

I. Introduction

A low-wage housekeeping staff member at a Bangalore business copies videos to his mobile phone from colleagues at work and plays them for his mother in the evening at their suburban home. An urban slum dweller helps out her neighbor in watching *Sivaji*, a recent Tamil movie, by operating her DVD player.

Alone, these are interesting individual narratives of and life and technology among India's working class. However, when seen in the context of the systems they compose, these stories are examples of a more unified phenomenon: human infrastructure.

Infrastructures are typically thought of as tangible artifacts at the periphery of our awareness: electric grids, optical fibers, computer networks, roads, and pipelines. They are substrates of technology over which applications are delivered. However, a broadened understanding of infrastructure is possible—one that includes shared social practices, flows of information and materials, and the creative processes that are engaged in building and maintaining these substrates. These infrastructures may be a combination of the physical, the institutional, the symbolic, and the human [1]. They are the underlying foundation of a social system constituted by the pattern of relationships of people, through various networks and social arrangements. Residents in a society depend on human infrastructure for a range of activities in their daily lives, i.e. for work, socializing, education, health care, entertainment, and so on [1].

In our work in low-income communities of India, we find the social and the technological facets of infrastructure to be in especially close proximity. In fact, in some cases, the social system may itself have become a substrate on top of which technological infrastructures can be built. These human infrastructures are in some ways more robust and pervasive than technology networks—they overcome several constraints in access and use, such as high costs of devices and content, instability of networks, textual, and numeric literacies, precarious electricity, and technological unfamiliarity. We find that resource constraints give rise to as well as shape these human infrastructures.

In this paper, we report on two examples of human infrastructures in settings familiar to ICTD. First, we present an ethnography of intermediated technology usage, and second, a quantitative survey of mobile media sharing practices, both in low-income, urban communities of Bangalore, India. In particular, we show how everyday practices in low-income communities demonstrate the importance of human infrastructure to technology access and use. Our hope in this mixed-method juxtaposition is to capture some of the complexities, causalities, and particularities of human infrastructures.

We borrow the analytical device of "infrastructural inversion"—foregrounding the backstage elements of work practice in developing and marginalized contexts globally—from Star and Bowker [2]. We attempt to foreground the social system of human actors, relationships, activities, spaces, networks, and goals that we present in our findings. The human infrastructure reading points to creative and subversive practices at play in the face of resource constraints. In turn, the 'design-reality gap'—the gap between current realities and design conceptions of the information system—may be narrowed [3].

Based on our results, as well as reflection on other well-known ICTD projects, we argue that the concept of human infrastructure bears special significance to the field of ICTD. We suggest that technological interventions may prove to be more productive if they take into consideration the underlying human infrastructures, which have existed prior to them and are actively being shaped by and shaping the technology.

Finally, we note that recent debates within ICTD have questioned the centrality of technology versus people [4]. We agree with Best and Bar [4] that rigid disciplinary boundaries are unhelpful, and suggest that human infrastructure may be a productive concept around which to construct a cross-disciplinary synthesis. As we shall demonstrate, human

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infrastructure straddles the technological and the social, demonstrates how deeply intertwined the two really are, and represents a potentially quite powerful vehicle for the realization of ICTD goals.

II. INFRASTRUCTURES

An infrastructure is an underlying substrate—a framework that enables a group, organization, or society to function in certain ways, such as the series of pipes, drains, and water sources that comprise a water system. Foundational work on the study of infrastructure as a subject unto itself is due to Star and Ruhleder [5], who defined the characteristics of infrastructures embedded in their social practices and institutions.

Specifically, they possess the following properties:

1) *Embeddedness*: Infrastructures are bound up with a host of pre-existing structures, both technical and social, which they depend on for identity and function.
2) *Transparency*: Infrastructures support tasks invisibly by being ready-to-hand and without needing to be assembled or reinvented for each task.
3) *Reach or Scope*: Infrastructures are not limited or confined to a single event or site of practice. They may be either spatial or temporal.
4) *Learned as a part of membership*: The elements of infrastructures, such as artifacts and organizational relationships, are internalized by the people that use them.
5) *Linked with conventions for practice*: Infrastructures interact with the shared norms of a community of practice, both shaping them and being shaped by them.
6) *Embodiment of standards*: Where conventions conflict between different infrastructures, interconnections are made through reliance on negotiated standards.
7) *Installed base*: New infrastructures are built upon older ones, and upon existing systems of support, funding, training, and expertise.
8) *Visible upon breakdown*: Infrastructures tend to be invisible to those using them unless and until they break down.

Infrastructures are traditionally conceived as invisible and ready-to-hand in the western discourse. In domestic life, Tolmie *et al.* [6] describe infrastructures as being unremarkable and difficult to discern in everyday work. We only become aware of infrastructures when they break down. They are constantly re-configuring themselves and are made locally stable through active engagement and coordination. Infrastructures are unevenly distributed and unevenly available.

While a majority of research studying infrastructures has focused on technological infrastructures such as grids or operating systems, much less has been said about social infrastructures [1]. Work by Lee, Dourish, and Mark is a notable exception [7]. They studied the growing phenomenon of scientific cyber infrastructures—large, computer mediated networks of scientists, laboratories, and research facilities conceived to support large-scale scientific inquiry. In particular, they highlighted the centrality of the social aspects of those networks, or in their words, "the arrangements of organizations and actors that must be brought into alignment" in order for real work to be accomplished. They called this facet of the system the "human infrastructure".

Other scholars have since studied human or social infrastructures in differing settings. Slattery examined the social and technological features of Wikipedia articles which help mediate the activity of fact building [8]. O'Neill *et al.* stress the centrality of humans, not technology, in explaining the difficulty of achieving consistent color reproduction in commercial printing processes [9]. Mark, Al-Ani, and Semaan describe how human infrastructure can be disrupted in a war zone, and how people turn to information technology in order to maintain their social connections in such situations [1].

But these authors are sure to point out that in focusing on the human side of infrastructure; they do not depart from Star and Ruhleder's original theoretical conception of infrastructure as a mix of the physical and the human. Rather, they seek to amplify the human side for the sake of analysis, given the relatively little attention paid to it in the past. We take the same stance. Being ICTD scholars, we are of course fundamentally interested in technology, and we thus do not seek to subtract it from our conceptual frame. Rather, we wish to highlight what we believe is the special importance of human infrastructures to ICTD projects.

By way of doing so, we turn to a review of prevalent ICTD projects which feature human infrastructure as an essential component.

III. HUMAN INFRASTRUCTURES IN ICTD

Though we are the first, to our knowledge, to bring the concept of human infrastructure to the field of ICTD, there is no shortage of ICTD research that demonstrates the importance of human relationships and connections to a successful technological endeavor. We review some such projects here. Some of the following projects stand out as relatively obvious examples of human infrastructure, while with others, the concept lies slightly beneath the surface.

The DakNet project is one which lends itself neatly to the idea. The project leveraged existing human transport infrastructures (busses, motorcycles, even ox carts) to transport data and provide basic Internet services for rural villages in several developing regions. While it could be argued that the underlying transport architecture is not solely human, and includes physical components such as buses, roads, and so on, it is clear that those infrastructures feature humans as a much more prevalent component than does, say, a fibreoptic network. For instance, a transport network is subject to the same causes for breakdown as a solely human infrastructure: illness, personal conflict, human error, and so forth. A fibreoptic network may be susceptible to these as well, but to a far lesser extent on a day-to-day basis. Therefore, we consider DakNet networks to be prime examples of human infrastructures in the spirit of this paper. The same could be said of the KioskNet system of Guo *et al.* [10].

A less obvious example of the centrality of human

infrastructure in ICTD comes from the MOSES project, a recent experiment in new media technologies and post-conflict reconciliation in Liberia [11]. The project created a walk-up-and-use video-sharing kiosk system for Liberians to share their views and thoughts on the issues of the day—an interactive platform for discussion in a nation of highly limited conventional communications infrastructure. Researchers in the MOSES project found that the system was commonly used by groups of people crowded in front of the machine. Knowledge of how to use the machine flowed among the members of the group—those already familiar with the interface assisted those still learning. Some interviewed users expressed deriving the confidence to use the machine by seeing others do it successfully with ease. Ultimately, it was found that the system was usable by almost all the users that attempted to use it. This was without any assistance from the researchers, and despite high rates of print and computer illiteracy in the country. At work here, we believe, was also human infrastructure. Existing relationships between users in the group, be they friends, family, or simply residents of the same village, were leveraged to help one and all explore a new and intriguing artifact. Again, technological success was due to existing human relationships—if the technology had somehow only allowed one user at a time, it would likely have been unusable for many.

The Digital Green project serves as a similar example where group dynamics are employed to support knowledge transfer through a digital medium. Farmers in rural India are encouraged to record videos describing various best practices in small-scale agriculture. Those videos are then played back for group audiences during special viewing events. The system has been nicknamed 'Farmer Idol', after the familiar series of TV amateur talent shows. Contributors are moved to share their knowledge and other farmers are persuaded to learn from them chiefly because of the human infrastructure—the personal relationships in small, close-knit villages—upon which the system is premised. The researchers report greater success with this social model than with traditional agricultural extension systems, where unknown experts are the ones doing the instructing.

Quantitative analyses of efficiency have also reaffirmed the power of human infrastructures in ICTD. Many ICTD projects have embraced mobile phone technology as a powerful means of gathering and transmitting socially useful data. Patniak *et al*. analyzed error rates associated with mobile phone data entry in India, comparing automated techniques (mobile phone forms and SMS messages) against dictation to human operators [12]. They found the human operators to be about an order of magnitude faster than either of the competitors (0.45% error rate vs. 4.2% and 4.8%, respectively). They also report that the expected cost of human operators is only slightly higher than SMS, and significantly lower than forms, owing to the low cost of labor in India. Based on these results, they argue that human operators may be a preferable and feasible solution, especially for data which demands high accuracy (such as health data). Here, a straightforward cost-benefit analysis has selected for human infrastructure, due largely to economic conditions—low-cost labor in contrast to high-cost technology—common to many ICTD projects.

A final example comes from the work of Ramachandran *et al*. on using mobile phone videos as a catalyst for change in rural healthcare practices. The authors noted that limited education, training, and status led to impaired performance on the part of rural health workers. However, rather than turn to technology as an informational agent, they relied on its persuasive and motivational qualities to improve both the services offered and the uptake thereof. Health workers were equipped with short videos about dangers to maternal health, and showed the videos to pregnant women, with encouraging results. The videos served as a concrete artifact around which discussion and learning could take place. We contend that in this case, the human infrastructure comprised of the health workers, pregnant women, and their families, was leveraged by the persuasive video program, rather than supplanted by it, as might have been the case if the researchers had seen the videos as a solely informational mechanism.

Table 1. Some prevalent ICTD projects and the human infrastructures central to their success.

Project	Human Infrastructure
DakNet [13]	human transport networks (busses, motorcycles, ox carts)
MOSES [11]	groups of kiosk users
Digital Green [14]	farmers and villagers in close-knit communities
Data entry accuracy: forms/SMS/voice [12]	human data-entry operators
Persuasive rural health [15]	community health workers and patients

These are just a few examples of ICTD projects where human infrastructure seems to play a central role. In the next sections, we explore two compelling human infrastructures that are not part of any particular institutionalized ICTD project, but that we have observed in situ, evolving organically in the everyday lives of our participants.

IV. STUDY 1: INTERMEDIATION IN SLUM COMMUNITIES

A. Methods

Our first study employed the ethnographic method in our inquiry of the role of technology in the everyday lives of two urban slums (Ragigudda and Nakalbandi) in Bangalore, India. The researcher spent four months in domestic and communal settings, observing 22 domestic workers. A range of methods were used—participant observation, semi-structured interviews, observation, surveys, scenarios, and budget exercises. The researcher spent time in NGO meetings, activist demonstrations, homes, work places, and third places, such as temples and water pumps. Through open-ended interviews, followed by semi-structured interviews and surveys, we uncovered technology

usage and development issues. Socio-economic data was collected to understand family structures, sources of income, education levels, assets, and other demographic backgrounds of our informants.

B. Findings

We present two cases that highlight the human infrastructure we observed. We employ two different modes of construction (borrowing from anthropologist George Marcus [16]) in infrastructure inversion—following a technology and following a person. We analyze the paths, conjunctions, and frictions of the human infrastructure and technological artifacts. Our goal in this articulation is to highlight the various use contexts as well as broader meanings of the technological interactions.

1) Following a technology: The mobile phone.

Following the circulation of technologies through different contexts sheds light on the technology itself as well as the users and localities that it comes in contact with. Our observation of the technology spanned one week. At the outset, we define an intermediary-user as a technologically-skilled or literate member who enables technology use for persons whose technology access is affected by non-literacy, lack of digital operation skills, financial constraints, and socio-cultural and empowerment issues including gender, employment, and social status, as listed in [17]. Various factors may affect access and use, such as fear of the technology, habits of dependency, or cost of owning a technology, as we discuss elsewhere.

Consider, for instance, the Nokia 2600 mobile phone found in Radhika's household. She is a 35-year old with two children (Mohan and Saraswati), aged 6 and 8 years. Her education stopped at 6th grade, when her parents moved from a southern village to the metropolis of Bangalore, in search of a better livelihood. Since then, she has worked as a domestic worker in various households, eventually hiking her salary to Rs. 3,500 ($70) by working in 3 households and a hospital. Her husband, Shankar, 40 years of age, had purchased the phone on discount from a local store in the Jayanagar residential area, a customary 'new good' during the harvest festival of Pongal. He works as a plumber. His 62-year old mother, Kangambika, also lives in the same household.

On a typical morning, the phone functions as an FM radio, sitting on top of the television. It is a dedicated player of religious hymns on the government-operated All India Radio station until 7 am. Afterward, it switches to film music on a private radio station, Radiocity. By 7:30 am, the radio function is turned off. In the background, Radhika, Shankar, and the two children get ready for work and school. Kanagambika makes some tea and packs lunch for the children.

Figure 1. The mobile phone (left) and Radhika at home (right).

The phone travels with Shankar to his first morning assignment. His phone rings again by 10 AM: two other households have plumbing issues. The second customer is an old contact. Shankar wants his wallpaper changed; he is bored with his old Ganesha wallpaper. The customer sends him filmstar Rajini's wallpaper via Bluetooth. Modifying the wallpaper requires English-language skills and Shankar does not possess these (being a 9th grade Tamil-language dropout). The customer helps him out by turning on the Bluetooth and modifying the background. The mobile phone, with the new wallpaper, travels home on Shankar's bicycle.

It is 2 pm. Shankar dozes off after his lunch. Meanwhile, Kanagambika wants to make a phone call to her sister who lives in a village near Madurai in the neighboring state. She has barely used the phone. She wakes her son up for help. Shankar dials the number for her and makes the call. By now, Radhika has returned home.

At 3 pm, the children return from school. By 3:15 pm, they head out to play with the neighbor child, Thangavelu. They come back home excitedly. They ask Shankar, "*Appa*, where is the phone?" He wants to know why they are looking for it. They say, "We want to play games on it." Shankar hesitates for a moment, but gives the device to them anyway. The children sprint outdoors and settle over a sewage slab. Thangavelu shows them how to play Snakes.

On the following day, at 4 pm, Radhika listens to a radio show, where the lively host is enticing the city of Bangalore to SMS their answer to the question, "Where is Meenakshi temple?" The winner receives prize money of Rs. 1000 ($25). Radhika knows the answer. It is in Madurai. There is a problem—she cannot text, since she is not literate. Her neighbor, Shanmugapriya, has studied up to 10th grade, with English as second language. Yes, she can help! Radhika immediately seeks her help in typing 'Madurai.'

One of these days, Radhika's cousin is getting married. The entire family is dressed up. Kanagambika and Radhika in their Kanchivaram sarees and Shankar in his white, polyester Veshti. The children are also decked up. Radhika plays an important role in the wedding, but they are getting late. Shankar wants to call Radhika's parents. But the phone is not working. The display is blank. They head over to Shanmugapriya, and borrow her phone to make the call. Her husband, who works as an electrician, repairs the phone by evening. A cable had moved a bit.

By applying the analytical lens of the human infrastructure, we see several interesting phenomena and practices here: The phone is appropriated as a communal object, within the bounds of a family. Therefore, as a fluid object [18], it comes into contact with several users and uses. Starting with its role as a family entertainment device in the morning, it transforms into a communication device for Shankar's plumbing business. It then acts as a 'stationary landline' for the family, only to quickly switch to a gaming device. Then it turns into a texting device. What does this tell us about the substrate that enables these uses? Different digital skills and textual literacy are required to successfully utilize the phone in these contexts. Changing the phone's wallpaper, helping Kanagambika make the phone call, game-skilling via a friend, texting the radio station, or repairing the display—they are all manifestations of the human infrastructure at work. Shankar, his employer, Shanmugapriya, her husband, and Thangavelu all act as intermediaries in various capacities. The beneficiaries are resourceful enough to find the right kind of help in carrying out the activities. The foundation of social relationships is leveraged in carrying out these activities.

2) Following a person: Rani's call-center connections

Following and staying with the movements of a person helps us trace the meanings and workings of them in and through the various contexts they participate in.

As a woman, Rani, 23, had the rare opportunity to study in college. She lives with her 10-year old sister, Radha, and widowed mother. The company she works for has provided her with a mobile phone so she can be contacted at nights, for her pick-up.

The results of Radha's board exams are out. Rani stays late at work following her night shift, so she can be among the first few lucky ones to check Radha's results online on her work computer. The board exam server routinely crashes when too many users log in. Radha scores 71%.

Radha wants to join a polytechnic, because education there is of shorter duration and cheaper than college. The following day, Rani checks out career options for Radha on the Internet.

It is a Monday, and it is Rani's off-day. Her neighbor, Meenakshi, is back from work (she works as a domestic worker) and she wants to make a phone call. Meenakshi's husband owns a phone, but he carries it to work. Social constructs prevent Meenakshi from openly owning a mobile phone, as in her world, women cannot give off the impression of being 'empowered' (although she is financially independent through her job). Meenakshi is 'empowered', however, although she cannot be conspicuous about it. She borrows Rani's mobile phone to call her mother when her husband is away at work. Sometimes Rani plays the latest film songs to Meenakshi. Sometimes Meenakshi cooks for her.

Rani's mother wants to watch the afternoon cookery show. But the television is set to DVD player mode from last night's movie-watching session. Rani switches to the show. But the audio is choppy. She connects to the external speakers they use for the DVD player.

A glimpse into the mundane activities of Rani's life highlights how she acts as an intermediary, affecting various people's (technological) lives. We see how Rani becomes a 'last-mile connector' [17], acting literally as a human link between an unconnected household and the Internet. Such instances challenge our traditional notion of last-mile as a technological telecom concept. Rani is the technological expert who is also literate. She is crucial in enabling technological use for several of the people in her social network.

There is another story at play here. Meenakshi's relations with Rani are subversive in nature. She overcomes the normative social constructs of the position of women in society, and ingeniously makes use of her neighbor's technology and skills in carrying out activities that are meaningful to her.

V. STUDY 2: MOBILE MEDIA SHARING

Our second study took place in the summer of 2009 in Bangalore, India, and examined a seemingly widespread practice, already mentioned in our first study, wherein mobile phone owners trade entertainment media (music, videos, wallpaper images, and other media) using peer-to-peer wireless Bluetooth file transfers.

It appears that phones capable of handling multimedia and supporting Bluetooth transfers are increasingly within the reach of Indian consumers, even those of modest income. As a result, the sharing behavior described here seems to be flourishing among cost-conscious consumers, since Bluetooth transfers are free, whereas downloading content using the mobile phone company networks can quickly consume closely guarded prepaid phone credits. Something of a community of practice has sprung up to support peer-to-peer sharing, including informal transfers of the technical knowledge required, content downloading services at mobile phones shops, and a host of innovative improvised techniques and practices to make best use of the technology within the prevailing constraints.

An in-depth qualitative examination of these sharing practices has appeared elsewhere [19]. In this paper, we describe a quantitative study intended to more precisely measure some of the phenomena observed in the earlier study. To our knowledge, this is the first study to examine mobile phone sharing practices quantitatively.

A. Methods

The survey was conducted by telephone using a snowball samping technique over a three week period in August 2009. A total of 270 people were called, and 170 either could not be reached or declined to participate. We stopped calling when 100 surveys were completed. Respondents were offered Rs. 50 ($1) in phone credits as compensation.[1]

Initial respondents were drawn from the pool of

[1] This was a convenient form of remuneration for a phone survey since phone recharging in India is usually done via text message by a licensed vendor—all that is required is the phone number and amount to be recharged. Thus we compiled daily lists of remunerations to be disbursed and dropped them off at a nearby mobile phone shop.

interviewees from an earlier study. Those participants, in turn, had been drawn from short preliminary interviews conducted with i) random passers-by in several Bangalore neighborhoods, and ii) support staff at Microsoft Research India. From that initial sample, we used a snowballing technique to grow our sample. Specifically, we asked each respondent to name all the people with whom they regularly shared files. Then (so as not to overburden the respondent) we randomly chose three from that set and asked for their phone numbers and permission to contact. We submit that this snowballing approach is appropriate for this study given our interest in the structure of the network. We also claim that this combination of random starting points plus growth through snowballing makes for an adequately varied and robust sample for this exploratory study. Previous social networks studies have used a similar sampling technique, e.g. [20,21].

Respondents were asked a series of general questions, including basic demographics, details about their phone ownership, and whether they ever downloaded multimedia content from the Internet. A set of questions was also asked for each of the three selected sharing partners, including contact information, nature of the relationship, and details on sharing behavior.

B. Results

Demographics. Out of 100 contacted respondents, mean income was Rs. 7445 ($149) per month (SD = 3369). This is slightly less than the average for urban India [13]. Median education level was 10 years. Reported occupations ranged from church pastor to web designer, but most were labor or service positions, as would be expected given the modest income levels reported. Almost all respondents were men (95%), which reflects the greater popularity of media sharing practices among men, especially in this demographic (female college students, on the other hand, seem more likely to partake). Mean age was 25.2 years (SD = 6.6), and 82% of respondents were in their 20s or younger. That said, 5 respondents were of age 40 or greater, suggesting modest adoption among an older generation.

Network overview. The node-link diagram in Figure 2 shows the network of sharing relationships produced by our study. Each white node in the diagram represents either a respondent or a respondent's sharing partner. Sharing partners shown in the diagram are only those who were randomly selected for elaboration, as described above (others cannot be shown since without their phone numbers we could not verify their uniqueness). Red nodes represent the Internet—that is, white nodes connected to red nodes correspond to respondents who reported obtaining content from the Internet.

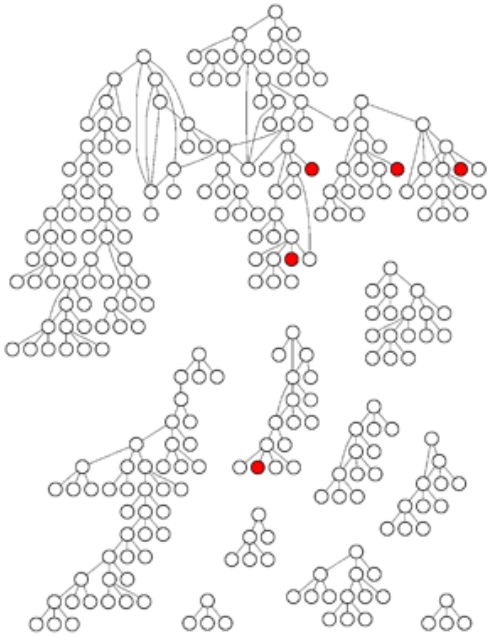

Figure 2. The sharing network layout.

The diameter (the length of the longest direct path between two nodes) of the network is 27 hops, while the size of the largest distinct component of the network is 139 nodes, or about 50% of all nodes. These statistics indicate that the sharing networks described here can be quite extensive and far reaching. In other words, while our survey stopped at 100 respondents, it seems reasonable to expect that we could have carried on to orders of magnitude more simply by way of our snowball sampling method.

On the other hand, the network has 10 distinct components, which is a reflection of our mixed sampling strategy. Were we to continue expanding each of the components, we expect that some of them would eventually link up. The average number of sharing partners reported by users was 4.3 (SD = 1.4)[2].

Connection to the Internet. As indicated by the graph, only 5% of respondents reported obtaining content from the Internet. This implies that the vast majority of sharers depend exclusively on person-to-person Bluetooth transfers for their content, and that many sharers are multiple hops away from an Internet connection. This is likely due to the cost of Internet access as opposed to free person-to-person sharing.

Geographic distance. Figure 2 shows the reported places of residence (by neighbourhood) of sharers within India (both those interviewed and those selected for elaboration). Since Bluetooth transfers require close physical proximity, sharing connections across distances imply that partners encounter each other while travelling around the city (e.g. to the workplace) or country (e.g. to the native village or relatives residences). A natural cluster in an around Bangalore is evident, as is a number of sharers well outside of Bangalore, including one as far as New Delhi (not shown). This suggests

[2] Note that this number is higher than the average degree of the graph Figure 2, since the graph shows only a subset of sharing partners, as described in the methods section.

that sharing connections can be far ranging, and that should this survey have been extended, it would likely have grown too many different parts of the country.

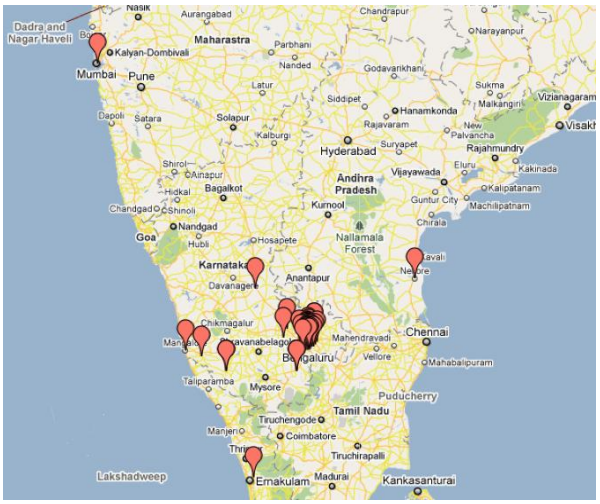

Figure 3. Geographic locations of respondents. A large cluster is evident around the city of Bangalore, but a considerable number of respondents came from outside that cluster, indicating the broad geographical reach of the network.

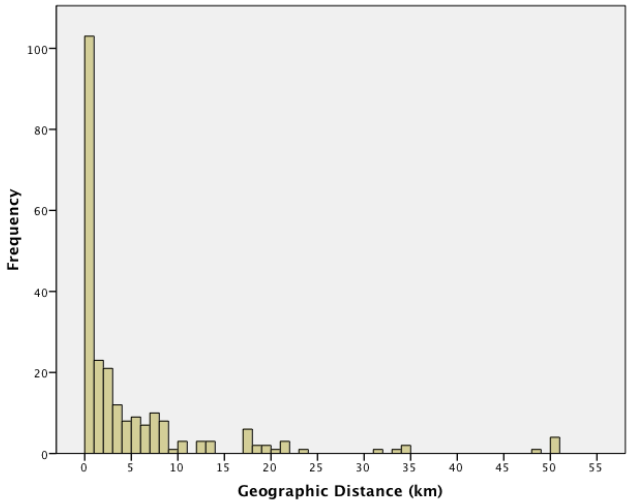

Figure 4. A histogram of geographic distances between sharing partners. As expected, a large number of partners are from the same neighborhood (0 km in distance); however, a plateau in the graph exists at medium distances, indicating a non-trivial number of medium distance trading relationships.

The geographic distances between sharing partners was also analyzed. Figure shows a histogram of such distances. By far the most common distance was 0 km, indicating sharing partners from the same neighborhood. However, past that initial spike, plateaus are evident from 1 km to 2 km and from to 3 km to 10 km. This suggests a non-trivial amount of sharing relationships spanning considerable distances. These may result from regular encounters, e.g. two sharers residing in far apart neighborhoods but traveling to the same place of work every day, or from occasional encounters, such as a city-dweller returning to his or her native village periodically. But in each case, we can be sure that a face to face encounter occurred at some point in time, since Bluetooth transfers require close physical proximity. What these pictures show, then, is a 'sneaker net' of great geographic reach.

Reciprocity. Respondents were asked to describe the reciprocity of each sharing relationship selected for elaboration, choosing from 'I mostly send to that partner' (1), 'we share about evenly' (0), or 'I mostly receive from that partner' (-1). By aggregating these scores over all links for each respondent, we can obtain a composite score representing net reciprocity. Figure shows a histogram of such scores for all 100 respondents. The data are clearly positively skewed, suggesting more people are net receivers (51%) as compared to 18% with even reciprocity and 31% net senders. Ultimately, this points to a small number of sharers acting as hubs, regularly obtaining fresh content and sharing it with multiple others.

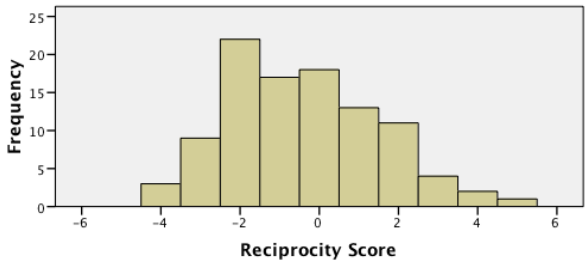

Figure 5. A histogram of reciprocity scores for respondents. The positive skew suggests more sharers are net receivers.

VI. DISCUSSION

As we have illustrated, social systems are leveraged in technological practices in highly local and contingent ways. The human infrastructure lens focuses our attention on the existing dependencies, conditions, and knowledges that will shape technology, its affordances and opportunities. Understanding the human infrastructure involves analyzing the relationship between the materiality of technology and the constellation of human actors, relationships, activities, spaces, and networks. We now locate the human infrastructure within the ICTD terrain, by providing a discussion of the processes of these infrastructures.

A. Processes

We articulate equivalents of technological processes in the human infrastructure, i.e., we highlight the ways in which the human infrastructure can approximate various system-level processes. Specifically we discuss the cases of usage, maintenance work, and diffusion. Such a formulation broadens our notions of design of an ICT4D intervention as one that is being introduced into a substrate of social relationships that may already be performing certain processes, which the intervention may try to achieve or disrupt in its

implementation.

1. Usage.

Several technologies come into fruition only with the help of the human infrastructure. Our point here is not that technologies find users; rather, we are emphasizing the importance of human agents in enabling technology use for *others* who may not typically own or access or use such technologies. Our intermediation cases discuss the vitality of such actors in technology access. Rani and Shankar enable technology use for members of their family. Rani achieves this in less obvious ways, such as accessing the Internet at work, and sometimes in more traditional (to the field of ICT4D) ways through collocated use. The MOSES project demonstrates the role of the existing relationships between users in the group in exploring a new and curious technology.

Such novel appropriations extend from existing practices embedded in an infrastructure. ICTD as a field has long understood the importance of designing for community, as a cultural principle or as a way to cope with resource constraints [22]. Community-centered design could be more productive if designers sought to understand the existing social norms and dependencies before intervention.

2. Maintenance work.

Technological environments in low-income communities are often prone to disruptions such as irregular electricity, low quality due to grey market goods, effects of heat and dust, or economic constraints affecting technology use. The human infrastructure steps in and 'keeps the system going.' When the technology breaks down, social networks are accessed to repair or fix. As we see in Shankar's case, his neighbor helps him out by repairing the phone. Rani helps her mother out by fixing the television. Technological experts in the mobile media case helped their contacts in the face of technical issues. CSCW researchers Star and Strauss [2] define articulation work as the "work that gets things back 'on track' in the face of the unexpected, and modifies action to accommodate unanticipated contingencies. The important thing about articulation work is that it is invisible to rationalized models of work." The lens of human infrastructure opens us up to the existing articulation work in ICT4D contexts.

3. Diffusion.

Recall that only 5 percent of mobile media users connect to the Internet. Only 36% of the women in the slums owned their own phones. However, through the process of diffusion, there are actually many more users than one. Through the use of micro Bluetooth networks, the mobile media users were able to create a pervasive human infrastructure that was robust. Their ingenious use of limited technical resources, i.e., the support staff accessed the Internet to download content, which is then shared with the rest of the social network interested in mobile media, demonstrates a calculated, deliberate interaction that is planned [23]

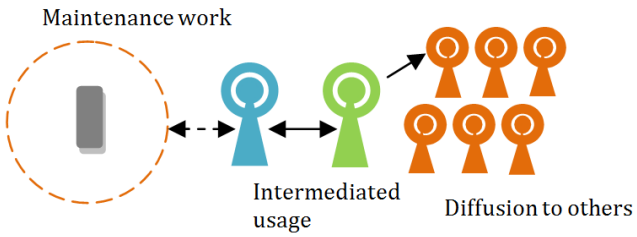

Figure 6. Diagrammatic representation of the systemic processes in an infrastructure.

B. Properties

Converting social, biological, political, and economic complexities into technical problems for welfare achievement is a thorny translation, because one has to be careful about not flattening the socio-cultural specificities. Employing the lens of human infrastructure alerts us to the existing arrangements and dependencies that operate in historical, political, social, cultural, and economic spaces. As anthropologist James Ferguson [24] argues in relation to the development problem, the answer to the question "what should they do" (referring to the "downtrodden" masses) is "they are already doing it!" The challenge, then, is to discover what, how, when, where and why are "they" doing it. As we have shown in our study findings, low-income communities are performing sophisticated and complex acts in ingenious and resourceful ways through the human infrastructure. Understanding and leveraging these infrastructures could prove to be a productive formulation of ICT4D design. Here, we discuss some of the properties of human infrastructures as derived from our fields.

1. Human infrastructures can be robust.

Back-dropped by technological disruptions, human infrastructures are relatively robust and elastic. They comprise a substrate of social relationships that are built upon foundations of trust. Not only do they serve as platforms for repairing technological infrastructures, in linking users and repair agents, but they are also capable of re-switching among themselves. For example, if a particular intermediary is not available, another person is sought if they are known to have the know-how and in the social network of the beneficiary. In the mobile media study, nuanced and varying sharing relationships led to the exchange of different kinds of media and switching to other social relations when media was not available from someone.

2. Human infrastructures may be pervasive, but take on different forms.

Human infrastructures in low-income communities are relatively pervasive in geographical distribution. This is because infrastructures are inter-connected. While different practices are embedded in different infrastructures, following non-uniform standards, and belonging to various communities of practice, they constitute a wide net that inter-operate with each other, sometimes reconfiguring and contesting with each other. For example, a community of chauffeurs shared a film

track with a community of electricians, creating a relatively pervasive substrate.

3. *Human Infrastructures can be low-cost.*

By cost, we refer to the additional expense in creating and maintaining a new thing or resource. Human infrastructures can already be engaged in cultural production, such as social capital or gossip. In both our sites, the act of sharing and providing was normally, but not mandatorily reciprocated, through various means, such as cooking or providing other media. By expanding the scope of the human infrastructure as not just being used in information and communication access (which are ICT4D's main concerns), but also in forms of cultural production helps us understand how they are employed in meaning-making, social investment and affecting the group culturally and symbolically. Such nuanced understandings open new doors for introducing technology in socio-culturally meaningful ways.

Employing the human infrastructure lens helps us design technologies in harmony with existing social, cultural, political, and economic processes. By asking how people conduct their affairs? How are rules made and enforced? What are the dependencies of various actors and groups? Where does technology fit within this landscape? Approaching the field with an open mind, a willingness to be surprised and learn something new and not to be overly deductive creates productive starting points for designers.

C. Opportunistic areas for ICT4D

So far we have highlighted the technical processes and properties of human infrastructures in relation to ICT4D. In this sub-section, we present opportunistic areas for human infrastructure use in ICT4D.

1. *Human infrastructures as usage resources.*

Leveraging social resources in ICT4D applications can influence the barrier to using and technical sophistication (if needed) of applications. Existing human infrastructure, with a few enhancements, could be used to overcome uneven digital and textual literacies and cost of ownership. For example, commuting is sometimes a group activity, wherein groups of people travel together to a common or close-by destinations. Creating applications for 'down-time' or 'killing time' that involves long hours of waiting, in culturally-sensitive ways (*i.e.*, not displace the gossip if it is meaningful to them, may make use of existing human resources in a context of established interpersonal trust.

2. Human infrastructures as networks.

By conceiving infrastructures as inter-connected pieces forming a larger whole, we can think of them as nodes and edges, as hubs and spokes, as having strong ties and weak ties, and as having key actors that enable or disable access to resources. Consider the case of mobile sharing networks and Internet. Due to several constraints, technological networks may not scale or face disruptions. By considering the human infrastructure as a network, we are provided with new possibilities for "network-based" applications, such as verification of content through trusted transmitters or spreading information to interested parties.

3. Human infrastructures as capacity building resources.

Human infrastructures could be used in creation and distribution of expertise and literacies. Collocated use is demonstrative [17] in nature, and may lead to learning by observing. Especially in the case of large-scale deployment, it is not practical for the application developer or support to provide immediate assistance, given the problems due to transportation or lack of other resources. For example, mobile phone credit sellers are often technical experts who stay updated with the latest technologies (activating, repairing, remixing, or downloading content). At the same time, they maintain a stock of relatively cheaper (through grey markets) and recent phones and other services. Customers that have an existing relationship with these store agents may comprise a system readily translatable to an ICT4D environment.

VII. CONCLUSION

In this paper we have posited an essential relationship between a relatively young and dynamic concept—human infrastructure—and the field of ICTD, itself also quite young and dynamic.

We have shown that the concept of human infrastructure permeates the ICTD space, as exemplified by several prevalent projects across a range of domains. We have further given two novel and compelling examples of human infrastructures at work in low income, developing communities; infrastructures which have come about entirely organically, and are of considerable size, scope, and robustness.

On the other hand, we realize that some ICTD projects may not need human infrastructure at their conceptual base. Such projects may focus more narrowly on important interface design issues, or on purely technological infrastructure challenges, or on still other areas outside the scope of human infrastructure.

We also stress that the specific term 'human infrastructure' does not form the core of our contribution. We acknowledge that much previous work in ICTD and elsewhere has studied and promoted the human aspects of socio-technical systems. Rather, we characterize our contribution as calling out the unique relationships between human infrastructures and technological infrastructures in many developing regions. These relationships, we argue, give special prominence to the human side of the equation. As such, it should be given equally special attention by ICTD researchers.

A second assertion made by this paper is that the concept of human infrastructure, and its repeated incarnation in the ICTD space, ought to further discourage those who would seek to establish disciplinary silos within the still emerging field of ICTD. Our research shows that in ICTD, perhaps more than most any other field, the social and the technological are fundamentally intertwined. To discount either one would be to ignore the great potential of the kinds of infrastructures we have described in this paper. We agree with Best and Bar [4] who, speaking of ICTD technologists and social scientists, say "to think that [the two groups] do not need to sit at the same conferences together, read each other's papers, understand the

methods and underlying principles of each other's work, and even collaborate on co-authored papers is equally worrisome." The prominence of human infrastructure in the technological landscape of the developing world demonstrates why this is true. To make use of resource of human infrastructure clearly requires the skill sets of engineers and social scientists both. We hope we have demonstrated in this paper that doing so represents such a formidable opportunity.

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