The Breaking Hand: Skills, Care, and Sufferings of the Hands of an Electronic Waste Worker in Bangladesh

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ABSTRACT

While repair work has recently been getting increasing attention in HCI, recycling practices have still remained relatively understudied, especially in the context of the Global South. To this end, building on our eight-month-long ethnography, this paper reports the electronic waste ('e-waste', henceforth) recycling practices among the e-waste recycler ('bhangari'[1]) communities in Dhaka, Bangladesh. In doing so, this paper offers the work of the bhangaris through an articulation of their hands and their uses. Drawing from a rich body of scholarly work on social science, we define and contextualize three characteristics of the hand of a bhangari: knowledge, care, and skills and collaboration. Our study also highlights the pains and sufferings involved in this profession. By explaining bhangari work through the hand, we also discuss its implications for design, and its connection to HCI's broader interest in sustainability.

CCS CONCEPTS

• **Human-centered computing → Ethnographic studies**.

KEYWORDS

electronic waste; recycle; tactile experience; ICTD

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[1]Electronic waste workers are known as 'bhangari' in Bangladesh

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1 INTRODUCTION

The increasing amount of e-waste production and the problems created by that have become one of the major threats for today's world [47, 83, 90]. With the fast changing trend of technology, people are frequently changing their electronic devices [18, 67, 96]. As a result, electronic waste is increasing at an alarming rate. In 2016, the amount of e-waste generated worldwide was 44.7 million metric tons, which is almost equal to the weight of 4500 Eiffel Towers [5]. Studies in Environmental Science and Public Health have warned about a wide range of risks associated with improper management and uncontrolled dumping of this e-waste [24, 32, 60]. While there are several policies for controlling the generation and circulation of e-waste [57, 59], many countries are failing to implement those and are having various kinds of environmental pollution due to e-waste. Furthermore, several studies suggest that there are uneven distributions in the generation and flow of e-waste among different regions of the world, and not every country is handling an equitable and just ratio of e-waste [14, 90, 90]. While the developed countries are generating more e-waste than the developing ones, the latter are often the receivers of the bigger portion of the e-waste [78, 90]. Hence, the problem of e-waste concerns both the environmental and ethical aspects of HCI.

For controlling the generation of e-waste, there are policies and 'common practices', some of which are country-specific and some are regional (such as WEEE, StEP, 3R) [90]. In most developed countries, manufacturers are responsible for taking back their broken devices and disposing of those in an environmentally friendly way [78, 90]. However, e-waste management has emerged as an independent business in other parts of the world. In most developing countries, e-waste businesses are small and medium-sized enterprises (SMEs) [90], and informal repairer and recyclers process and recycle most of the e-waste [13]. Most of them are unable to make the best use of e-waste with their limited resources. At the same time, they are routinely exposed to toxic and

hazardous conditions at their workplace. Nevertheless, these e-waste workers are often recognized as the driver of second-hand electronic markets in those developing countries [86]. Hence, e-waste has become an important topic of research both for HCI and ICTD communities.

There are several threads of work within HCI that are active toward reducing e-waste directly and indirectly. One of those threads is focusing on the sustainable consumption of technologies, and designing various techniques to make people consume and waste wisely [19, 22]. Another rich body of HCI work is concentrating in the practice of repair – a skill-based work to fix an artifact and put it back to its use (see [3, 4, 38–40, 69], for example). However, electronic recycling has not yet received much attention in HCI so far. At this point, it is important to distinguish the act of repair from recycling. Repair is defined as a set of tasks associated with restoring the functionality of a broken device. On the other hand, electronic recycling refers to a series of activities that convert a broken electronic device to a set of materials valued for other purposes (other than the electronic device it was before). These activities often involve dismantling, breaking, separating, melting, and re-purposing among others. These are important and yet understudied and undervalued human interactions with broken computing systems that are immensely important to address the menacing e-waste problem that the world is facing today.

To this end, we present the findings of our eight-month long ethnography on the e-waste management practices in Dhaka, Bangladesh to generate some important lessons for HCI. Besides presenting a detailed description of the people, place, tools, and techniques that are involved in e-waste management processes in Dhaka, we intend to make three core contribution to HCI research from our ethnography. First, this paper describes the occupational hazards associated with informal e-waste processing in the Global South, and shows ways for HCI to address this problem. Second, this paper presents bhangari work as an understudied site for understanding tactile experiences with broken computing devices, which shows novel ways for tangible interface research to grow. Third, drawing from social science and anthropology, this paper positions 'hand' as a subject of analysis to understand craft-based work, which will allow HCI to better understand professions that require regular tactile interaction with computing devices.

2 RELATED WORK

Repair, Recycle, Sustainability, and HCI

HCI has a central interest in design and use of technologies that has often sidelined our post-use moments with a technology: obsolescence, malfunctioning, repair, recycle, etc. However, a growing body of work in HCI and related fields has recently started shedding light on those moments from different vantage points. This line of HCI scholarship often builds on some early HCI works from social scientists. For example, Lucy Suchman's seminal work on *'Plans and Situated Actions'* has shown how the malfunctioning of technology needs to be tackled by humans and has paved the path for future studies on repair [81]. Steve Jackson has built on that and developed the idea of a 'broken world' that needs to be addressed with care, creativity, and collaboration [37], and he identifies repair as one such site of care and collaboration. HCI work on repair has since grown in recent years through a series of ethnographic work on repair conducted in different parts of the world [80]. For example, Jackson et al. have studied the technology repair practices in rural Namibia and have shown how the local knowledge, tools, and techniques are connected to several broader international networks [40]. Ahmed et al. have studied repair work in Dhaka, Bangladesh, and documented the art, craft, knowledge, and skills involved in their profession [4]. Houston has conducted an ethnography on the repair work in Kampala, Uganda, and found the care and innovation required in their work [29]. Besides these, some other related studies have focused on different other aspects of repair, including privacy [2], valuation [30], craft [39], knowledge [38], infrastructure [70], and design [95].

While this growing body of scholarship is illuminating various aspects of repair work, recycling has not yet got enough attention in HCI. Because of its frequent connections with repair, recycling has often come to the discussion as a supporting activity for repairing. For example, both Houston's and Ahmed's studies have mentioned how objects that are 'beyond repair' are sold to the e-waste collectors. Ahmed et al. have also looked into the social organization of the 'bhangaris' in Dhaka, and reported how they learn from the other members of their community [4]. However, these and a few other similar studies that have mentioned e-waste collection, have not gone deeper into the work of recycling.

Breakdown, repair, and recycle are also connected to the recent movement of sustainability within HCI. Sustainable interaction research has often focused on persuasion as a dominant way to drive people toward responsible behaviour (such as [52]). Blevis has built on them and presented a gateway for HCI to approach sustainable interaction design [7]. However, DiSalvo et al. called for widening this view beyond persuasion through interaction, and incorporating the whole life-cycle of technology including the social and cultural contexts surrounding it [8]. Remy and Huang have extended this discussion and incorporated obsolescence, breakdown, repair, and recycle in their recommendation to sustainable HCI research [66]. To this end, Maestri and Wakkary have argued that design should make recycling easy for the users [51]. Huang and Truong's have shown how situated information

can help people take a better decision for recycling [31]. Other researchers have tried to connect electronic waste to creativity [43] and art [41]. Furthermore, Taylor et al. have documented the stories of electronic recycling practices among the low-income communities in Australia [82]. However, none of these studies focused on the situated practices of recycling, especially in the informal settings of a developing country.

While e-waste recycling has not been discussed much in HCI, it has been getting increasing attention in environmental science, public health, and geography. For example, Ni et al. discussed the human exposure to chemical components emitted from e-waste, and the health and environmental implications as a result of this [56]. Wath et al. reported the current e-waste scenario in India and the health and environmental risks of e-waste [87]. The studies show that e-waste flows from the west to the east and the threats posed by the uncontrolled handling of them. A few studies have explored the e-waste management and provided insights into the practice. From an ethnographic study in Dhaka, Lepawsky and Billah have reported on five channels–resale, refurbishing, remanufacturing, recycling, and dismantling–through which electronic waste and their parts are valued and revalued in the local markets with the creative knowledge, practice, and expertise of local people [48].

In the field of occupational health, we find a rich body of work focused on studying the hands of the workers (see [45, 58, 75, 77], for example). A majority of the works have concentrated on the 'safety' of the workers' hand. For example, Pink et al. [62] have observed the material culture of gloves, water, and gels among healthcare workers as they use the hand as an analytic tool. They have defined a 'safe hand' to explain the work of the healthcare worker, documented their responsibilities and practical challenges of their hands, and discussed corresponding safety measures. Such analysis deepens our understanding of the works that are heavily hand-based and involve skills in operating tools.

Knowledge, Skill, Materiality, and Hand

The idea of considering *hand* as a tool for understanding subjective realities has its root in western phenomenology. In his ontological categorization of *'being'* [26], Heidegger has suggested three classes of entities in this world: (a) ready-to-hand entities (*equipment*): properties of which are taken as granted as we use them in everyday life, (b) present-at-hand entities (*things*): which are given conscious attention independent of how they are used in everyday life, and (c) unready-to hand entities: which are broken or malfunctioning. Thus, he has positioned hand (in its broad meaning) at the center of our knowledge and consciousness. For Heidegger, 'thought' is embodied in how body functions; and in that functioning, hand acts as a thinking tool for humans [25]. Ingold has extended this argument to crafts-based work and suggested that the hand can also 'tell' a thought, in a way similar to how voice does [33]. Drawing our attention to the history of craftsmanship, Ingold shows how thoughts come into a conversation with materials through our hand and shape our material world. Sennett has further advanced this idea and has shown how craftsmanship is developed through a relationship between a hand and a tool [73]. MacKenzie, based on her ethnography in New Guinea, has shown how making such skilled 'hands' is often a part of a culture that defines their material realities [50]. These and many other important works in anthropology, philosophy, psychology, media studies, and social science (see [23, 27, 54, 62, 92], for example) have demonstrated how hand has played a central role in shaping human civilization by knowing, telling, making, and caring, among others.

The rich body of scholarship in the materiality of knowledge has also influenced our understanding of science and technology, and our interactions with them. For example, Michael Polanyi's celebrated work on 'tacit knowledge' reveals how some kinds of knowledge (for example, balancing a bicycle) can only be 'felt' and are hard to express [64]. Harry Collins has shown how that tacit dimension of knowledge intermixes with 'explicit knowledge' to construct our reality [15]. Lave and Wenger show how such skill-based knowledge is sustained in a 'community of practice' through apprenticeship [46]. In recent years, many HCI scholars have focused on this material aspect of knowledge to study craft [71], skills [38], art [42], innovation [49], and other material practices [69], too. However, the hand has hardly been put as the central subject of inquiry in conceptualizing the materiality of work, other than studying gesture-based interfaces [44]. Based on our earlier discussion on hand, we argue that it is important to conceptualize the hand of a craftsman both for better understanding their work through its construction and performance, and for improving the work itself by designing supporting tools. Both of these objectives align themselves well with the long-standing interest of workplace HCI [9]. In this light, this paper aims to develop a deep understanding of the profession of e-waste processing through an understanding of the hand of the workers.

HCI, Tangibility, and Hand

Central to the design of numerous technologies was manipulating the capabilities that our hands provide: grabbing, sensing by touching, pinching, throwing, moving, creating gestures, holding, squeezing, to name a few. HCI technologies are no exception. Many long-standing input devices, inter alia mouse and keyboard, that are usually connected to the GUI based fixed computing stations, are operated by hands. A rich body of HCI work has focused on the ergonomics of hands to make these devices more effective and efficient

(see [10, 16], for example). In the early nineties, a trend in moving computing from fixed stations to making it pervasive over the fabric of our everyday life gave birth to the field we now call 'ubiquitous computing' [88]. In that movement, the idea of 'graspable user interface' [20] became essential to interact with the new kinds of computing devices including mobile phones and laptops. Later, the invention of the touchscreen brought some radical changes in our experiences of interacting with those devices with our hands. Today, we see many innovative interactions between hands and ubiquitous computing devices that involves touching [91], moving [84], shaking [28], grasping [94], and brushing [72], among others.

In a parallel body of work, Hiroshi Ishii and his colleagues introduced another new approach of making computing ubiquitous by making things intelligent and responsive to touch - a genre of interfaces we know as 'tangible user interfaces' (TUI) [35]. They were motivated by the rich modalities of human knowledge and skills that are constructed by touching the physical world [35]. They focused on allowing the users to "grasp & manipulate" the foreground bits to sense and tell, and by coupling those with corresponding bits in the background, they made the interface react [35]." Later Ishii re-articulated his vision saying, *"The goal is to empower collaboration, learning, and decision making through digital technology while taking advantage of our human ability to grasp and manipulate physical objects and materials"* [34]. In the last two decades, we have seen this vision coming true through various fascinating work on TUIs (see [36, 85, 89], for example).

As we can see, all these important works are mostly focused on the use and experience of hands with 'functional' artifacts and designs the moments when technology works. However, the experience of touching and sensing a broken technology and the hand-based skills and crafts that require to repair and recycle them do not receive enough attention. However, a vast number of people around the world who repair and recycle electronics have that experience and their profession depends on how effectively their hands interact with broken devices. We argue that the experience of interacting with broken objects with a hand is radically different from the experience of swiping on a smartphone screen, selecting the menu on a tangible tabletop, or even clicking a mouse button. Ahmed et al's work on the art and craft of repairing has shed some light on the tacit knowledge involved in such tasks [4], but has not articulated how a repairer's hand is constituted of many such tacit knowledge and skills. Considering the hand as a tool for understanding the process, experience, care, and risks of a profession has still remained understudied. This paper aims to develop that knowledge and contribute to HCI knowledge in tangible experience.

3 METHODS AND FIELDSITES

Our study consists of eight months of ethnography at four main e-waste markets in Dhaka, Bangladesh: Nimtoli, Elephant Road, Islambag, Zinzira. The first phase of ethnography was conducted between May to August 2017, while the second phase took place from May to August 2018. All the authors of this paper were born in Bangladesh and raised in Dhaka. Our local friends facilitated our access to these four e-waste markets. We were introduced to two bhangaris in each market. We developed a good relationship with them and others that they introduced to over the time through a deep engagement with their work and informal conversations. Following the snowball sampling [6], we studied a total of 50 bhangaris in the four e-waste markets. The bhangaris included workshop owners, workshop labourers, e-waste collectors, roadside e-waste dismantlers, and middlemen. All the bhangaris that we met in the four markets were men, age ranging from 12 to 60 years.

Our study involves a set of ethnographically-informed techniques including semi-structured interviews, biography, contextual inquiry, ethnomethodological observation, photography, and videography. We conducted semi-structured interviews with each of our participants where we inquired about their demography, educational background, work experience, training, and the challenges and prospects of their profession. The interviews allowed us to get access into a rich set of knowledge regarding the past, present, and future of bhangari communities in Dhaka. We further deepened our knowledge by making biographies of 10 experienced bhangaris. The biographies documented their major life events, career paths, and future goals. Besides deepening our understanding of this community, we also focused on the very task of e-waste processing. For this, we conducted more than 40 hours of observation of bhangari work at seven workshops. We took an ethnomethodological [17, 21] approach in our observation to focus on the use of their hands in e-waste processing. We noticed every movement, gesture, action, and the reaction of their hand when they worked. This observational study was accompanied by contextual inquiry that provided explanations of their work. For supporting our study, we also took more than 200 photographs and recorded more than 7 hours of videos of bhangari's work.

We conducted the interviews in Bengali and wrote down in our notebook. The observational data was also collected using a notebook. We translated and transcribed the qualitative data into English. The interviews and observational data were considered as themes based on the sections of the handwritten interviews and observations, which is similar to the grounded theory approach [79]. The video data was coded and matched against the corresponding observational notes.

Figure 1: From left to right: (i) a bhangari carrying his sack for collecting broken electronics; (ii) front side bhangari workshop at Nimtoli; (iii) inside a bhangari workshop at Elephant Road;

This study was approved by the ethics review committee of the authors' institutions.

Fieldsites. Nimtoli, Elephant Road, Islambag, and Zinzira are the four main e-waste markets in Dhaka. Nimtoli is located in the older part of the city (known as 'Old Dhaka'), and is the oldest and the biggest of these four. This market is a collection of densely located old workshops on both sides of a narrow and busy street and its even narrower and busier branches. Those streets are so narrow that it is difficult for a car to pass through them, and the workshops often make them even narrower by putting their stuff on the streets. Moreover, some mobile e-waste workers often sit on those streets and work. As a result, traffic congestion is very common there. This makes it difficult for the business establishments to carry e-waste in larger lots. Despite these limitations and inconveniences, this market has sustained and even thrived in the last twenty years. This market is a home for large- and mid-sized e-waste workshops that buy obsolete or broken electronics; sell semi-functional devices to retail customers.

Elephant Road e-waste market is, on the other hand, located in a comparatively more 'sophisticated' part of the city, and surrounded by large electronic markets, and two large electronic repair markets (Nahar Plaza and Eastern Plaza). As a result, a "buy-fix-recycle" ecosystem is seen there where people know each other very well. The e-waste workers in Elephant Road work closely with the local electronics and repair shops, collect broken items from there, dismantle them, and sell the broken pieces either to the repairers or to the buyers of second-hand products. Unlike Elephant Road, Islambag e-waste market houses the factories that are buyers of plastics in large lots from e-waste markets. Those factories process plastic materials. Finally, Zinzira is well known for metal processing business and full of small enterprises that buy metals of different kinds, melt them, and use them for making utensils, wires, and machinery. In addition to the e-waste markets and material processing factories, we also studied several "out of market" e-waste shops.

Bhangaris. Informal e-waste recycling in Bangladesh connects people with different ecological nodes that are commonly called Bhangaris (a Bengali word meaning 'one who breaks'). Some bhangaris start the bhangari business in a local neighbourhood. Some of them take this profession temporarily or seasonally. Others make it their permanent profession, eventually promoting themselves to having a permanent workshop. Once they have a permanent workshop, they only buy broken electronics from poorer bhangaris. We have seen workshops that are vaguely defining their territories in the neighbourhoods by employing hawkers, oftentimes by a weekly and monthly basis. These workshops also employ bhangaris for breaking the electronics and selling them. Ahmed et al.'s work has shed some light on the work of these bhangaris [4], especially the knowledge they need in their work. However, a deep understanding of bhangari communities, their work, skills, and workplace hazards have not been discussed in the literature.

A typical bhangari workshop is usually a small 5 feet by 10 feet room, full of broken electronics. Bhangaris have their own way of organizing stuff in their workshop. Piles of large functional electronics are pushed to the back in the workshop. The piles of electronics that bhangaris will be working on soon are put in the front. Bhangaris sit on chairs or a wood piece placed on the floor. Around them, within a reachable distance, are the testing and breaking tools: power sources, tool sack, hammer, accumulating sack, weight machines, etc. They intentionally break the cement floor in front of their sitting places so that they can get extra control over the electronics when they place them on the broken floor. If the workshop-front is not a busy street, bhangaris put some e-waste on the street and work temporarily sitting there. Some bhangaris do not have a shop at all and work on the streets.

There is no woman in the bhangari market although there are some women who help bhangaris in collecting broken electronics. We did not find any bhangari who passed elementary school (although, there were very few cases of educated temporary bhangari who were helping their close

relatives in the market temporarily). Some people inherit the bhangari business from their parents as a family business. We also found several clusters where bhangaris came from the same district, often through familial recommendations.

4 E-WASTE PROCESSING IN DHAKA

Our study has documented the typical journey of a broken electronic artifact in Dhaka from the moment of its breakdown to some common reincarnations of its components in various forms. During this process, based on its type and condition, a broken device may be re-purposed or dismantled, and its parts may be taken apart, tested, sorted, re-used, broken, melted, or simply discarded. In this section, we present how these incidents actually happen in the four e-waste markets of Dhaka that we have visited.

Collection. The e-waste workshops collect discarded electronics from all over the city in various means. Some workshops have employees who collect them from offices, repair shops, and households, while the others (usually the large ones) buy them in a lot from smaller workshops. A large number of bhangaris roam around the city, visit households and offices, and buy discarded electronics. While buying discarded electronics from households, bhangaris often exchange grocery items including salt, sugar, oil, or cookies. While it is often uncertain when a household will have a broken device, large offices often discard their old electronic devices periodically as a part of their regular maintenance. Thus, they produce a large amount of broken, semi-functioning, malfunctioning, old, and outdated computers, printers, scanners, etc. on a regular basis. The bhangaris buy those in a very small price from them, often at a flat rate by weight. Some institutions, especially the government-owned ones, sell discarded electronics through auctions. (In most cases, the auctions are pre-fixed through bribes, nepotism, or political influence, as we have heard from our participants). Besides these, bhangaris also visit the repair shops. If an electronic device is 'beyond repair' and its parts are unusable, the repairers usually sell those to the bhangaris. For carrying and transporting e-waste, bhangaris use light baskets on their head, wheelbarrows, sacks, or large trucks.

Testing and Sorting. After collecting the discarded electronics, bhangaris accumulate them in their workshop. The next task is testing and sorting. Not all broken devices have equal values to them. For example, some devices are less broken than the others, and can even be sold in the second-hand market at a low price after some manipulations. Again, some broken devices have more functionals components in it that can be re-purposed than the others. Hence, bhangaris apply their intuition, experience, and expertise (details in the later part of the paper) to examine and categorize these devices. Then the discarded devices are sorted in different piles in their workshop.

Re-purposing and Improvisation. Bhangaris often fix devices to sell them in the second-hand markets. However, the fixing work of bhangaris is very different from that of a repairer. For a repairer, fixing usually means bringing back a lost functionality of a device. However, bhangaris do not try that. Instead, they check if somebody could use the device without that particular functionality. For example, if the mic of a mobile phone is broken, then repairers try to fix that, so the mic works again. However, bhangaris check if the phone can perform the other functions correctly. If so, then they brush up the phone to give it a 'newer look,' and then sell that in the second-hand roadside markets.

Often times the broken device may not have any usable function. In those cases, bhangaris check if they can re-purpose that device for making something else. For example, we have seen a bhangari take apart a broken desktop and found the fan working in it. He added a couple of additional blades to the fan to make it work like a table fan, which he later sold to a customer. Such improvisation and re-purposing is a common practice in the bhangari markets, which aligns itself with similar findings in other places in the Indian subcontinent (see [65], for example).

Along with their bare hands, bhangaris make use of some tools while they re-purpose and improvise electronics. Some of these tools come from the devices they break (example: sharp glass, plastic, wire, etc.), while they buy the rest from second-hand markets. For re-purposing or improvising electronic parts, they often need to change the shape, look, size, among other properties of the device. Their task of changing such properties rests on the tools and the way the use those: a hammer for bending or straightening metals or plastics; brushes for cleaning or painting; hammers and hacksaws for cutting or making things brighter or glaring; screws or pins for drilling are just a few examples of their use of tools in this phase.

Dismantling and metal extraction. For the devices that cannot be re-purposed, bhangaris dismantle them. They use knives, hammers, scissors, pliers, and many such tools to break those devices. A common strategy that we have observed in this work is separating different materials. For example, glass, plastic, rubber, copper wire, steel, and woods are stored separately after dismantling a broken laptop. In Elephant Road and Nimtoli, the bhangaris stop here and sell these materials separately to different merchants who then carry them to Islambag, or Zinzira. In Islambagh, and Zinzira, they further process these materials. In Islambagh, there are boilers for melting plastics and making plastic pellets. In Zinzira, they melt the metals and extract gold, copper, and other materials out of them. There is a ornaments industry located close to Zinzira, and they goldsmiths there often buy gold from bhangaris.

In this step, some useful manual tools and techniques aid bhangaris for categorizing materials and pre-processing them before selling. For example, they use drillers, testers, wrench spanners, chisels, as they open, break, or demolish electronics; brushes or hacksaws to understand the color of a very wired out metal by scratching it; magnets to categorize metals, to mention a few.

Dumping. While some e-waste workshops that are affluent enough to afford large spaces to store goods, most stores are tiny, and the bhangaris struggle to find space for storing their goods. So, the bhangaris pursue an optimum strategy to decide which of the electronics, tools, and materials they will keep for their business. We found that the e-waste market treats some extracted electronic materials as "less profitable" than the others. For example, glasses that come out of monitors have little value to them. In addition to such less-profitable parts, some parts are considered "not usable", too. We have seen them throwing away plastics and metals that they cannot sell. Bhanagaris usually dump those electronic components to the nearby dumpsters.

International export. There are small and large scale factories in Dhaka that routinely buy e-waste from bhangari markets. However, besides selling e-waste to the local markets, some bhangari workshops accumulate e-waste in larger volumes and sell those to their international buyers. However, we have not found any international buyer buying plastics, rubbers, metals, or raw materials in any form. Their main interest is in motherboards, capacitors, diodes, power supplies, unbroken casings, and mobile phone displays. International buyers do not often show up in the market. They employ local agents who communicate to and negotiate with local bhangaris. These agents often offer extra benefits to the bhangaris, including higher prices than the usual local market prices, reimbursement for storage arrangement, and small gifts. For unconfirmed reasons, such international buyers usually like to remain invisible in the bhangari market (we have not met any of them). However, people are well aware of their presence, and they know their local partners. Rumour has it that all of the e-waste goes to China through these international buyers, where wastes are processed and used for making other products.

5 THE HAND AND THE WORK OF RECYCLING

Hand plays a central role in the work of bhangaris. Most bhangari works depend on assessing a broken device, improvising it, dismantling it, and melting it - all through the different skilled operations of their hand. In this section, we present a deeper insight into the role of hands of the bhangaris in the e-waste processing chain in Bangladesh.

Knowing Hands

We borrow the definition of *'Knowing Hands'* from David Rosenbaum [68], who has shown how human beings are different from other species because of their use of hands for acquiring a rich set of knowledge and processing them. For bhangaris, their hand is the device with which they sense, test, and assess the worth of a broken device. This is often done through touching, brushing, rubbing, shaking, waving, and other skillful performance of their hand. Our observations reveal how a bhangari's hand is used as a tool for identifying, feeling, measuring, weighing, perceiving, and counting - to know about broken devices. When a broken electronic device arrives at an e-waste workshop, the first task that a bhangari does is checking the broken device to assess a number of things: approximate worth of it, whether it can be sold in the second-hand market, whether it has any functioning component in it, how difficult it will be to dismantle it, etc. For this initial checking, they typically use different techniques with their hand. For example, the following case illuminates how Mr. Akkas, a 55 years old experienced bhangari in Nimtoli market uses his hand to assess the value of a broken motherboard.

Case 1: Testing a motherboard. Mr. Akkas is testing a motherboard that he has just bought from a boy who had collected that from a nearby repair shop. He is holding the motherboard in this left hand and brushing the thumb of his right hand on the upper surface of it. "It is old, probably damp", he just said softly. Now he has started touching the ICs on the board using his thumb and index finger. While touching each of the ICs, he is testing if that IC comes off easily with a little pull. One black IC has just been pulled off in this process. "Told you, this is board is a bad one", he says. After a while, he has now started itching the surface of the board along with a copper line of the board. The thin green cover of the board is coming off along that line as he is itching. Then he starts brushing his index finger over the little brown surface that has got exposed now. "It has some metals inside, though", he says to himself. He then looks at me and says, "It is hard to get a good board these days. You don't make a lot of money out of these ones."

Bhangaris also weigh a device with their hands to guess the proportion of costly materials (i.e. irons, copper, zinc, etc.) in it. They often run their hands through different surfaces of a device and shake it to guess the history of that device, too (for example,'how old', 'how roughly it was used', 'is there a broken part hidden inside it', etc.). The following case demonstrates one such example:

Case 2: Testing an electronic flask. A customer comes to the workshop of Mr. Quddus with an old electronic flask which apparently looks like the one that is used for heating water up to a certain temperature. Mr. Quddus takes the flask for

Figure 2: Handworks of bhangaris (from left to right): (i) a bhangari is opening a laptop hard disc with a knife; (ii) a bhangari is pulling out ICs from a mother board with a needle; (iii) a bhangari is breaking a computer motherboard.

an initial check. He weighs the flask taking in his right hand and hangs the flask using his four fingers except for the thumb. Now Mr. Quddus hangs it again using his index finger. He gets back to the customer, negotiates the price, and buys it. Mr. Quddus gets back to me and says, "See, the only feature I will consider in buying this flask is its weight. If I get lucky, I can get a functioning flask and get a good price selling that. But, I must assume first that the flask is broken and can't be fixed; otherwise, why would they sell it to me? right? ... In that case, the only things here that I can sell out of it are irons and plastics. To see how much they are worth, it is important to take them [small electronic devices like a flask] in my hand and weigh. Heavier weight means there are more materials inside of it." Mr. Quddus continues to recheck the flask for its functionality after the customer leaves the shop. Mr. Quddus connects the flask with a power supply and sees if it runs: it does not. He runs his bare hands on the cylindrical surface of the flask to clean it using his fingers on the patches and smaller surfaces. Then he grabs the flask vertically and shakes it up and down. At the same time, he thumps it, while explaining to me why - "Do you hear any sound when I am shaking it? This is how we know if any part has been dislocated inside, or if a wire is disconnected. If we hear something, we open the flask and fix that." He does not hear any sound. As the next step, he opens the flask and runs his fingers on the electronic parts and wires on the circuit board, "sometimes, a device or wire is disconnected and you don't find it from shaking. When you do this [running the finger], it is likely that you will identify the disconnected portion. On the other hand, sometimes doing this will just clean the joints and make the connections on the circuit board better ... and the device may become functional." Mr. Quddus reconnects the circuit board, but the flask still does not work. So, he decides to break the flask and sell its parts.

Caring Hands

We build on Sarah Pink's famous work on "The Safe Hand" [61] to describe the 'caring' quality of a bhangari's hand. Pink, in her work, has beautifully demonstrated how safety is constructed in the hand of a hospital nurse through a conscious practice of social norms. We bring that notion of care to define a *'Caring Hand'* to identify the moments of a bhangari hand that protects both the electronics and their own body. We argue that a bhangari's hand embodies care - a combination of safety, caution, and improvement. This care is reflected in the ways they hold, tilt, shake, bend, or even break the devices. There are two main aspects of this care. First, a bhangari uses his hand in such a way that the important parts of the device that they want to keep and later sell do not break. Second, they also make sure that they do not hurt themselves while interacting with broken objects. The example below shows how Mr. Hasan's (40 years old) hand demonstrates care while removing an IC from a motherboard.

Case 3: Removing an IC from a motherboard. Mr. Hasan is removing ICs from the motherboard of a monitor ... one by one ... systematically. These ICs are important to him, and the removal process is pretty delicate. If enough attention is not paid, the ICs may break and they won't have any value in the market. However, he also needs to apply some force as the joints are very strong. ... Hasan first holds the IC with two of his fingers very softly. Then he makes a gentle pull and checks if the IC comes off. It doesn't. Hasan makes the second attempt with a slightly stronger pull. The IC still doesn't come off. Now he increases the force a little bit and makes his third attempt. This time the IC moves a bit. It seems the legs of the IC have moved a little. Hasan now gently moves the IC a little back and pulls that again, a little stronger this time. The IC almost comes off. One of its legs is still loosely attached to the body of the motherboard. Hasan, very patiently, makes one more light pull. This time the IC comes off.

This and many other examples show how bhangaris' fingers move in a way that a delicate internal connection of a monitor is not damaged, how their grip exerts just the right amount of pressure to break the plastic cover of a UPS battery

while keeping the rest intact, how they drive a knife through a rubber wire so that the copper inside is not damaged, just to name a few. Our observation documents numerous such examples of caring that the hand of a bhangari extends to the broken devices. At the same time, a bhangari's hand cares about themselves and the other workers in the workshop. The following case shows how an experienced bhangari, Mr. Akkas, uses his hand with care to protect himself from an electric shock.

Case 4: Re-purposing a CRT monitor. Mr. Akkas is working on a CRT monitor today. This monitor was discarded because a 'green object' inside it was broken, he tells me. But he has found that green object in another CRT this morning, which looks good to him. He is now trying if he can replace the damaged green object with the new one, and make the monitor work. For this, he has to keep the monitor connected to the power supply. This is a risky operation and he knows it. He may get an electric shock if he touches some parts of the board with his bare hand. With one finger of his hand, he keeps making light small touches at different points on the body of the board to find where 'there is a shock' ... He senses something on the heavy side of the board and quickly moves his hand away. "This is where the shock is". Akkas looks at the thin towel on his shoulder; the towel seems wet with his sweat. He puts off that towel and keeps looking around. He finds a piece of cloth near the tool sack. The cloth is dry and looks dusty. Mr. Akkas wraps his right hands and holds that green piece as he gets ready to set it on the board. He says, "I got a shock from a similar device a few days ago. Whenever I see a device like this, I wrap up my right hand with this piece of cloth so that my hand does not get in touch with electricity. I also do the same when I break the electric heaters; these operations are very risky."

We have observed many similar incidents where they use their hands for protecting themselves from getting electric shocks, cuts, heat, or pain. Taking together, the hand of bhangari is also a hand for protection and care. With their hand, a bhangari ensures that he extends his care to the broken object so that each of its components gets its best value in the market. The same hand also protect themselves and the people around them.

Skilled and Collaborative Hands

Building on Richard Sennet's celebrated work, *"The Craftsman"*, we define a *'skilled hand'* as a hand that is built for crafty work through a long history of deep engagement with tools [73]. We extend this idea of *skilled hand* to define the moments when a bhangari hand performs crafts with tools alone or in collaboration with fellow bhangaris. Much of bhangari work is primarily based on hands and the skills of using it. Some bhangari tasks which require advanced skills are challenging even for a veteran bhangari. Such tasks often require maintaining proper inclination of a board, balancing two ends, and holding the right angle for cutting, bending, or folding, or breaking an object to a certain degree. For example, while breaking a large flat motherboard or an electronic module of such type, bhangaris need to incline and position the motherboard in certain angles with the base. For such tasks, a skillful performance of the use of hands, along with proper use of tools, is required. Below is an excerpt from our fieldnote where we report how Mr. Razan (36 years old) uses the skills of his hands to extract a rectangular piece of wire that is stuck between the picture tube and casing of a monitor.

Case 5: Skillful demonstration in an wire extraction. [...] Mr. Razan is extracting a multi-patch wire around a picture tube. The wire is connected to the picture tube with a plastic tightener in three spots–in the middle, and in two corners–in each of the four sides. He takes a small plier in his right hand and pinches the wire in the corner of the picture tube and then twists it. The wire does not seem to be coming out. It turns out that a rubber tightener has blocked the wire. Mr. Razan holds the tube with his left hand to keep balance. He grabs the tightener, strengthens his grip with the pliers in his right hand and twists it strongly. The tightener cuts down in the corner. Mr. Razan now moves his left hand down to the wire, holds it with his fists, and shakes it both vertically and horizontally. Now Mr. Razan drives his hand to the other corner on the same side of the wire. He cuts the tightener at the other corner the same way he did that before. As the plastic tighteners for one side are separated, Mr. Razan pulls the wire vertically so that it comes out from the picture tubes. In pulling the wire, he uses the pliers for the places where he finds the wire is stuck, and finally extracts the wire from the other three sides of the rectangular piece.

This is an example of how a skillful bhangari hand is used in performing challenging tasks: by operating the tools accurately and keeping up with the speed and rhythm of their daily workload. If the bhangari is skillful and the task is small, he can do that alone. Otherwise, a bhangari needs an extra hand. For collaborating with others, his hand needs some different skills. Below is a case where Mr. Ripon (28 years old) and Mr. Rana (17 years old) try to identify the problem of a motherboard:

Case 6: Collaboration for enhanced capability and efficiency. Mr. Rana is fixing a motherboard today with a senior member of the workshop, Mr. Ripon. Mr. Rana opens the motherboard and connects it to a power source, while Mr. Ripon is closely looking at the motherboard to see if there is anything unusual: cases like a spark, cracks, or something else. Mr. Rana holds the motherboard vertically, while Mr. Ripon pokes the motherboard's machineries to see if there is any loose or open connection. Mr. Ripon wants to check a small switch-like a knob, while he instructs Mr. Rana to take a multimeter reading.

Mr. Ripon moves his hands towards the knob to press it. However, Mr. Ripon cannot reach the knob as Mr. Rana is blocking the space while connecting the knob. Mr. Ripon now takes a screw diver to get through space between Rana's two hands and presses the knob. The device starts running fine. Now, Mr. Ripon runs his hand through the surface of the motherboard. He finds something unusually hot that he identifies as a faulty item.

While accuracy, quality, and efficiency are important for bhangaris, for the sake of business, they also need to be quick and efficient. They cannot keep broken electronics idle for a long time in their limited space of workshops. On the other hand, the bhangari market is highly competitive; every bhangari is trying to make their own position bigger there. For these reasons, novice and unskilled, or even skilled bhangaris are needed to help the skilled ones. Over time, as novices become more skillful through apprenticeship, they look for having their own business.

6 PAINS AND SUFFERINGS

If the hand of a bhangari extends care, it endures pains, too. In an unprotected work environment without proper tools and training, this bhangaris are exposed to various kinds of psychical risks. Their hands bear many of these risks. Most of the Bhangaris' hands have become hard, black, often swollen, and with marks of old and new injuries in multiple places. Here, we present a set of very common pains that a bhangari hand frequently have.

Cut. Broken objects often have sharp edges or broken piece of glass or metals that cut the hands of bhangaris. Cut is probably one of the most common accidents that all bhangaris have. It happens every now and then. During our observation of their work, bhangaris got their hands cut 13 times[2]. These cuts were minor, and sometimes there was no bleeding, too. However, on some occasions, cuts can be severe, too. We have seen multiple cut marks in some bhangaris' hands. A couple of them shared with us the corresponding stories. One of them said,

"I was new then. I was checking the inside of an electric flask. I did not know that there was a sharp edge inside the throat of the flask. I entered my hand inside and rotated the flask hard. Oh! The sharp edge cut my hand from here to there (pointing to the start and end of the cut mark). The cut was so deep that flesh came out. I shut my eyes in pain ... It took one month to recover. I have to take injections, too." (Mr. Khan, 44 years, Elephant Road)

Bhangaris also get their hands cut by sharp wires, knives, pointed ICs, and many such objects that they encounter every single day. Our observations show that many of these objects may contain elements that can come in touch with their blood through such cuts, which can later result in serious problems. However, we have not seen any awareness or concerns among them regarding this.

Figure 3: Unprotected handling of toxic materials with hands

Electric Shock. Electric shock is another common pain that a bhangari receives very frequently. During our observations, we have seen them checking electronic devices with their fingers and getting shocked multiple times (one incident is described in Case 4). Most of the times, their hand receives electric shock either when they test a device, or when they try to re-purpose it. While we could see a clear expression of pain in their face when they receive a shock, we found none of them concerned about it. One of them said,

"I am shockproof. I am like "current man". Current passes through me, but doesn't harm me." (Mr. Shariful, 33 years, Elephant Road)

All the bhangaris seemed to have accepted electric shock as 'a part of their work'. While most of these shocks were minor, we have also heard one story of a bhangari who died of a heavy electric shock a few years back while testing a power supply board. Although there was no noticeable concern among the bhangaris regarding such electric shocks, they can cause many short to long-term damages to their nerve system, brain, eye, and many other organs. A high voltage shock may claim their life, too.

Exposure to harmful chemicals. Broken electronics often contain many chemical elements that are harmful to human skin. They include lead, cadmium, furans, etc [74]. Bhangaris do not only work with the materials with their

[2]we offered them first aid care, but they ignored

bare hands but also work with almost all day long. In several occassions, we found the hand of the bhangari smeared with blackish substances as they were working with the electronics. "Most of these 'chemicals' emit from motherboards and batteries", one of them explained to us. In some cases, bhangaris use octane to wash the boards and thus they need to touch octane, too.

Some bhangaris complained to us that this exposure to chemicals caused several problems to their hand. One of them extended both of his hands to us and showed his palms. The hand was hard, black, and swollen. He said,

"I do not know what they put in these machines, but I ruined my hand after coming to this job. My hand is hard and numb now. I cannot sense small things. My hands also itch a lot. I had an infection in my hand last year that took 2 months to recover ... there is a pain inside, too. I feel like I am poised ... and this is not only me. Ask anybody who is doing this for a long time. You lose your hand in this profession because there is poison in these machines that you cannot see."

Besides cuts, electric shocks, and chemical exposures, a bhangari hand often gets bruises as they come in contact with rough surfaces of broken devices. We have also met bhangaris whose hands were burnt as they touched a very hot surface of a device. Taken together, the hand of a bhangari endures various kinds of pains and sufferings. While some of its injuries are minor, many of those could have long-term impact on their health. However, we have not observed any protective measures for their hands in any of the four sites that we visited. Furthermore, there was not much awareness among them regarding the health impact of such injuries.

Occupational hazards in e-waste processing is a well-studied problem in Occupational Health, Public Health, and Environmental Science [63, 76, 87]. This situation becomes even riskier when e-waste is processed in an informal sector without proper protection. However, our study shows a burgeoning growth in e-waste in the e-waste markets of Dhaka as the country is converting itself to 'Digital Bangladesh'. Tons of digital technologies are being imported to local markets every day, and tons of them are converting into e-waste every day, too [1, 48]. Since space is scarce in Dhaka, with more e-waste, these markets are becoming more and more congested and thus unhygienic. Also, more and more bhangaris are coming to the profession, many of whom are teenagers (we have even met many boys who said they were 11 years old). Thus the socio-economic condition of the bhangari market, the economic ambition of the country accompanied by local politics, and the global growth in the use of computing have made layers of socio-technical complexities around the occupational hazard in e-waste handling that will require many deeper investigations.

7 DISCUSSION AND CONCLUSION

In the sections above, we have presented the electronic recycling practices in the main four e-waste markets in Dhaka, Bangladesh. We have shown how bhangaris, the e-waste workers, collect, sort, dismantle, and dispose broken electronics step-by-step. We have further focused on the role of the hand of bhangaris to deepen our understanding of their work. We have demonstrated how the hand of a bhangari is used to know, extend care, and perform collaborative and skillful work in this profession. Finally, we have also reported the pains and suffering of their hand due to various injuries and exposure to harmful chemicals. This study thus provides a deep understanding of bhangaris' interaction with broken computing devices, and open up new scopes for HCI in both design and theory fronts.

First, our work documents the informal process of e-waste management, an area that has been under-explored in HCI. This paper joins the growing body of work on the after-use phase of digital technologies in informal markets in the Global South, and demonstrates the important human factors involved in it. Through an articulation of handworks, our study shows how bhangaris' skills, experience, art, craft, knowledge, and suffering are involved in the e-waste management in Bangladesh. We note that bhangari works are often undervalued (our own study shows bhangaris are often neglected in the society), but they contribute significantly to sustainable digital consumption. Our study also shows how bhangari markets are also a place of innovation, repurposing, and improvisation, which supports similar observations in other places in the global south [11, 12, 65]. While such innovation in the repair market is often confined within producing novel electronics, bhangaris innovate all kinds of artifacts - starting from looking glass to the toothpick, and from paperweight to hair comb. Hence, we posit that bhangari work should be considered as an important site for innovation and sustainability studies in HCI.

Second, our work demonstrates an unsafe working condition for the bhangaris. We have also discussed the socio-technical complexities around this problem of occupational hazards in bhangari work. We call for HCI research to take a deeper look into this issue, along with the ongoing policy initiatives coming from other disciplines [55, 78, 90]. HCI research can focus on designing safe tools, techniques, and workplaces that will protect the bhangaris from the physical harm associated with recycling broken electronics in different phases. Considering the social and economic conditions of the bhangaris, design of such artifacts should be inexpensive and culturally appropriate. Besides such direct design interventions to bhangari work, we can also design technologies to create mass awareness, and a nation-wide movement to persuade the government to make policy and enforce laws

that are required to ensure a safe working environment for this vulnerable and marginalized population in Bangladesh.

Third, our study brings to the fore the tactile experiences of touching the broken electronics - a barely explored area in HCI. HCI's central focus on 'design' and 'use' of technology has mostly confined the experience of touch within these two phases of the life-cycle of a technology. As a result, a rich set of experiences that take place when people touch a non-functioning, malfunctioning, or broken technologies have not gotten enough attention in HCI. This paper intends to draw the attention of HCI researchers of tangible interfaces and ergonomics to the tactile experiences of the bhangaris while interacting with the broken electronics. We argue that a research that may stem from this work can benefit HCI research on tangible interfaces in various ways. For example, by extending the designer's vision from use to after-use phase will allow them to take into account the tactile experiences of the electronic waste workers in their design, as also indicated by Maestri and Wakkary [51]. Novel technologies can be built that are equally friendly for the users, repairers, and recyclers. Furthermore, many of the tactile experiences and hand activities of bhangari work can introduce many novel interactions in HCI. For example, twisting, pinching, rubbing, or bending an electronic device may introduce new modes of interactions with computing devices that are not much prevalent today.

Fourth, in this study, we have used *hand* as the center of our analysis of bhangari work. There are many professions, especially art and craft works, that are mostly done by hand. Hence, the hand has long been a center of interest for social scientists and anthropologists [27, 53, 54, 93]. While many works require our active and skillful interactions with computing devices through hands, it is still a relatively an underused method of understanding human-computer interaction in HCI research. It should be noted that a long-standing HCI work on ergonomics looks at hand in a very functional dimension (and measure comfort, ease, efficiency through performances). However, the hand that we propose to study goes far beyond that and encompasses the emotional, artistic, skillful, emotional, and political dimensions of work. In this paper, by putting the hand at the center, we have shown how different modes of a hand constitute the work of breaking computers and how a rich set of human emotions and social contexts are attached to them. Studying hands will provide a detailed explanation of the skills involved in a work, and the politics and emotions associated with them. We argue that such findings are valuable in designing better technologies that embody tangible experiences of users, by leveraging the functional and emotional dimensions of work.

REFERENCES

[1] Fazle Rabbi Sadeque Ahmed. 2011. E-waste management scenario in Bangladesh. In *WEEE/E-waste management workshop on take-back system*. 13–15.

[2] Syed Ishtiaque Ahmed, Shion Guha, Md Rashidujjaman Rifat, Faysal Hossain Shezan, and Nicola Dell. 2016. Privacy in Repair: An Analysis of the Privacy Challenges Surrounding Broken Digital Artifacts in Bangladesh. In *Proceedings of the Eighth International Conference on Information and Communication Technologies and Development*. ACM, 11.

[3] Syed Ishtiaque Ahmed, Shion Guha, Md Rashidujjaman Rifat, Faysal Hossain Shezan, and Nicola Dell. 2017. ICTD 2016| Privacy in Repair: An Analysis of the Privacy Challenges Surrounding Broken Digital Artifacts in Bangladesh. *Information Technologies & International Development* 13 (2017), 14.

[4] Syed Ishtiaque Ahmed, Steven J Jackson, and Md Rashidujjaman Rifat. 2015. Learning to fix: knowledge, collaboration and mobile phone repair in Dhaka, Bangladesh. In *Proceedings of the Seventh International Conference on Information and Communication Technologies and Development*. ACM, 4.

[5] Cornelis P Balde, Vanessa Forti, Vanessa Gray, Ruediger Kuehr, and Paul Stegmann. 2017. *The global e-waste monitor 2017: Quantities, flows and resources*. United Nations University, International Telecommunication Union, and International Solid Waste Association.

[6] Patrick Biernacki and Dan Waldorf. 1981. Snowball sampling: Problems and techniques of chain referral sampling. *Sociological methods & research* 10, 2 (1981), 141–163.

[7] Eli Blevis. 2007. Sustainable interaction design: invention & disposal, renewal & reuse. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 503–512.

[8] Hronn Brynjarsdottir, Maria Håkansson, James Pierce, Eric Baumer, Carl DiSalvo, and Phoebe Sengers. 2012. Sustainably unpersuaded: how persuasion narrows our vision of sustainability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 947–956.

[9] Graham Button and Wes Sharrock. 2009. Studies of Work and the Workplace in HCI: Concepts and Techniques. *Synthesis Lectures on Human-Centered Informatics* 2, 1 (2009), 1–96.

[10] Stuart K Card, William K English, and Betty J Burr. 1978. Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for text selection on a CRT. *Ergonomics* 21, 8 (1978), 601–613.

[11] Priyank Chandra. 2017. Informality and Invisibility: Traditional Technologies as Tools for Collaboration in an Informal Market. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, 4765–4775.

[12] Priyank Chandra, Syed Ishtiaque Ahmed, and Joyojeet Pal. 2017. Market practices and the bazaar: Technology consumption in ICT markets in the global south. In *Proceedings of the 2017 CHI conference on human factors in computing systems*. ACM, 4741–4752.

[13] Xinwen Chi, Martin Streicher-Porte, Mark YL Wang, and Markus A Reuter. 2011. Informal electronic waste recycling: a sector review with special focus on China. *Waste Management* 31, 4 (2011), 731–742.

[14] Silicon Valley Toxics Coalition and Basel Action Network. 2002. Exporting harm: the high-tech trashing of Asia. *The Basel Action Network, Seattle* (2002).

[15] Harry M Collins. 2001. Tacit knowledge, trust and the Q of sapphire. *Social studies of science* 31, 1 (2001), 71–85.

[16] Annabel Cooper and Leon Straker. 1998. Mouse versus keyboard use: A comparison of shoulder muscle load. *International Journal of Industrial Ergonomics* 22, 4-5 (1998), 351–357.

[17] Andy Crabtree, David M Nichols, Jon O'Brien, Mark Rouncefield, and Michael B Twidale. 2000. Ethnomethodologically informed ethnography and information system design. *Journal of the American Society for Information Science* 51, 7 (2000), 666–682.

[18] Maheshwar Dwivedy and RK Mittal. 2010. Future trends in computer waste generation in India. *Waste management* 30, 11 (2010), 2265–2277.

[19] Annie T Fang, Rahan Khozein, Sergio M Mendez-Baiges, and Eunice Y Shin. 2009. eXtend: reducing e-waste through redistribution of local it resources. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems*. ACM, 2817–2822.

[20] George W Fitzmaurice and William Buxton. 1997. *Graspable user interfaces*. University of Toronto.

[21] Harold Garfinkel. 1967. Studies in ethnomethodology. (1967).

[22] Alex A Gartland and Paulina Piasek. 2009. Weigh your waste: A sustainable way to reduce waste. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems*. ACM, 2853–2858.

[23] Patrick Haggard and J Randall Flanagan. 1996. *Hand and brain: the neurophysiology and psychology of hand movements*. Elsevier.

[24] Michelle Heacock, Carol Bain Kelly, Kwadwo Ansong Asante, Linda S Birnbaum, Åke Lennart Bergman, Marie-Noel Bruné, Irena Buka, David O Carpenter, Aimin Chen, Xia Huo, et al. 2015. E-waste and harm to vulnerable populations: a growing global problem. *Environmental health perspectives* 124, 5 (2015), 550–555.

[25] Martin Heidegger. 1968. What is called thinking? (1968).

[26] Martin Heidegger. 2010. *Being and time*. Suny Press.

[27] Robert Hertz. 2013. *Death and the right hand*. Routledge.

[28] Lars Erik Holmquist, Friedemann Mattern, Bernt Schiele, Petteri Alahuhta, Michael Beigl, and Hans-W Gellersen. 2001. Smart-its friends: A technique for users to easily establish connections between smart artefacts. In *international conference on Ubiquitous Computing*. Springer, 116–122.

[29] Lara Houston and Steven J Jackson. 2016. Caring for the next billion mobile handsets: opening proprietary closures through the work of repair. In *Proceedings of the Eighth International Conference on Information and Communication Technologies and Development*. ACM, 10.

[30] Lara Houston, Steven J Jackson, Daniela K Rosner, Syed Ishtiaque Ahmed, Meg Young, and Laewoo Kang. 2016. Values in repair. In *Proceedings of the 2016 CHI conference on human factors in computing systems*. ACM, 1403–1414.

[31] Elaine M Huang and Khai N Truong. 2008. Breaking the disposable technology paradigm: opportunities for sustainable interaction design for mobile phones. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 323–332.

[32] Jingyu Huang, Philip Nti Nkrumah, Desmond Ofosu Anim, and Ebenezer Mensah. 2014. E-waste disposal effects on the aquatic environment: Accra, Ghana. In *Reviews of environmental contamination and toxicology*. Springer, 19–34.

[33] Tim Ingold. 2013. *Making: Anthropology, archaeology, art and architecture*. Routledge.

[34] Hiroshi Ishii. 2008. The tangible user interface and its evolution. *Commun. ACM* 51, 6 (2008), 32–36.

[35] Hiroshi Ishii and Brygg Ullmer. 1997. Tangible bits: towards seamless interfaces between people, bits and atoms. In *Proceedings of the ACM SIGCHI Conference on Human factors in computing systems*. ACM, 234–241.

[36] Hiroshi Ishii, Craig Wisneski, Julian Orbanes, Ben Chun, and Joe Paradiso. 1999. PingPongPlus: design of an athletic-tangible interface for computer-supported cooperative play. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*. ACM, 394–401.

[37] Steven J Jackson. 2014. 11 Rethinking Repair. *Media technologies: Essays on communication, materiality, and society* (2014), 221–39.

[38] Steven J Jackson, Syed Ishtiaque Ahmed, and Md Rashidujjaman Rifat. 2014. Learning, innovation, and sustainability among mobile phone repairers in Dhaka, Bangladesh. In *Proceedings of the 2014 conference on Designing interactive systems*. ACM, 905–914.

[39] Steven J Jackson and Laewoo Kang. 2014. Breakdown, obsolescence and reuse: HCI and the art of repair. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 449–458.

[40] Steven J Jackson, Alex Pompe, and Gabriel Krieshok. 2012. Repair worlds: maintenance, repair, and ICT for development in rural Namibia. In *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work*. ACM, 107–116.

[41] Laewoo Kang, Taezoo Park, and Steven Jackson. 2014. Scale: human interactions with broken and discarded technologies. In *CHI'14 Extended Abstracts on Human Factors in Computing Systems*. ACM, 399–402.

[42] Laewoo Leo Kang and Steven Jackson. 2018. Collaborative art practice as HCI research. *interactions* 25, 2 (2018), 78–81.

[43] Sunyoung Kim and Eric Paulos. 2011. Practices in the creative reuse of e-waste. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2395–2404.

[44] David Kirk, Andy Crabtree, and Tom Rodden. 2005. Ways of the hands. In *ECSCW 2005*. Springer, 1–21.

[45] Mary G Lankford, Teresa R Zembower, William E Trick, Donna M Hacek, Gary A Noskin, and Lance R Peterson. 2003. Influence of role models and hospital design on the hand hygiene of health-care workers. *Emerging infectious diseases* 9, 2 (2003), 217.

[46] Jean Lave, Etienne Wenger, and Etienne Wenger. 1991. *Situated learning: Legitimate peripheral participation*. Vol. 521423740. Cambridge university press Cambridge.

[47] Josh Lepawsky. 2015. The changing geography of global trade in electronic discards: time to rethink the e-waste problem. *The Geographical Journal* 181, 2 (2015), 147–159.

[48] Josh Lepawsky and Mostaem Billah. 2011. Making chains that (un) make things: waste–value relations and the Bangladeshi rubbish electronics industry. *Geografiska Annaler: Series B, Human Geography* 93, 2 (2011), 121–139.

[49] Silvia Lindtner, Garnet D Hertz, and Paul Dourish. 2014. Emerging sites of HCI innovation: hackerspaces, hardware startups & incubators. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 439–448.

[50] Maureen Anne MacKenzie. 1991. *Androgynous objects: string bags and gender in central New Guinea*. Vol. 2. Taylor & Francis.

[51] Leah Maestri and Ron Wakkary. 2011. Understanding repair as a creative process of everyday design. In *Proceedings of the 8th ACM conference on Creativity and cognition*. ACM, 81–90.

[52] Jennifer Mankoff, Deanna Matthews, Susan R Fussell, and Michael Johnson. 2007. Leveraging social networks to motivate individuals to reduce their ecological footprints. In *System Sciences, 2007. HICSS 2007. 40th Annual Hawaii International Conference on*. IEEE, 87–87.

[53] Brian McDonough. 2017. The hands have it: tactile participation and maximum grip in the aviation sector. *Qualitative Research* (2017), 1468794117748252.

[54] Shaun Moores. 2014. Digital orientations:"Ways of the hand" and practical knowing in media uses and other manual activities. *Mobile Media & Communication* 2, 2 (2014), 196–208.

[55] Hong-Gang Ni and Eddy Y Zeng. 2009. Law enforcement and global collaboration are the keys to containing e-waste tsunami in China.

[56] Hong-Gang Ni, Hui Zeng, Shu Tao, and Eddy Y Zeng. 2010. Environmental and human exposure to persistent halogenated compounds derived from e-waste in China. *Environmental Toxicology and Chemistry* 29, 6 (2010), 1237–1247.

[57] Innocent C Nnorom and Oladele Osibanjo. 2008. Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries. *Resources, conservation and recycling* 52, 6 (2008), 843–858.

[58] Denise M Oleske and Jerome J Hahn. 1992. Work-related injuries of the hand: data from an occupational injury/illness surveillance system.

Journal of community health 17, 4 (1992), 205–219.

[59] Francis O Ongondo, Ian D Williams, and Tom J Cherrett. 2011. How are WEEE doing? A global review of the management of electrical and electronic wastes. *Waste management* 31, 4 (2011), 714–730.

[60] Oladele Osibanjo and IC Nnorom. 2007. The challenge of electronic waste (e-waste) management in developing countries. *Waste Management & Research* 25, 6 (2007), 489–501.

[61] Sarah Pink, Jennie Morgan, and Andrew Dainty. 2014. The safe hand: Gels, water, gloves and the materiality of tactile knowing. *Journal of Material Culture* 19, 4 (2014), 425–442.

[62] Sarah Pink, Jolynna Sinanan, Larissa Hjorth, and Heather Horst. 2016. Tactile digital ethnography: Researching mobile media through the hand. *Mobile Media & Communication* 4, 2 (2016), 237–251.

[63] Violet N Pinto. 2008. E-waste hazard: The impending challenge. *Indian journal of occupational and environmental medicine* 12, 2 (2008), 65.

[64] Michael Polanyi. 2009. *The tacit dimension.* University of Chicago press.

[65] Nimmi Rangaswamy and Nithya Sambasivan. 2011. Cutting Chai, Jugaad, and Here Pheri: towards UbiComp for a global community. *Personal and Ubiquitous Computing* 15, 6 (2011), 553–564.

[66] Christian Remy and Elaine M Huang. 2015. Addressing the obsolescence of end-user devices: Approaches from the field of sustainable HCI. In *ICT innovations for sustainability.* Springer, 257–267.

[67] Brett H Robinson. 2009. E-waste: an assessment of global production and environmental impacts. *Science of the total environment* 408, 2 (2009), 183–191.

[68] David A Rosenbaum. 2017. *Knowing hands: The cognitive psychology of manual control.* Cambridge University Press.

[69] Daniela Rosner, Jean-François Blanchette, Leah Buechley, Paul Dourish, and Melissa Mazmanian. 2012. From materials to materiality: connecting practice and theory in hc. In *CHI'12 Extended Abstracts on Human Factors in Computing Systems.* ACM, 2787–2790.

[70] Daniela K Rosner and Morgan Ames. 2014. Designing for repair?: infrastructures and materialities of breakdown. In *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing.* ACM, 319–331.

[71] Daniela K Rosner and Kimiko Ryokai. 2009. Reflections on craft: probing the creative process of everyday knitters. In *Proceedings of the seventh ACM conference on Creativity and cognition.* ACM, 195–204.

[72] Kimiko Ryokai, Stefan Marti, and Hiroshi Ishii. 2004. I/O brush: drawing with everyday objects as ink. In *Proceedings of the SIGCHI conference on Human factors in computing systems.* ACM, 303–310.

[73] Richard Sennett. 2008. *The craftsman.* Yale University Press.

[74] Alejandra Sepúlveda, Mathias Schluep, Fabrice G Renaud, Martin Streicher, Ruediger Kuehr, Christian Hagelüken, and Andreas C Gerecke. 2010. A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: Examples from China and India. *Environmental impact assessment review* 30, 1 (2010), 28–41.

[75] Barbara A Silverstein, Lawrence J Fine, and Thomas J Armstrong. 1986. Hand wrist cumulative trauma disorders in industry. *Occupational and Environmental Medicine* 43, 11 (1986), 779–784.

[76] Deepali Sinha-Khetriwal, Philipp Kraeuchi, and Markus Schwaninger. 2005. A comparison of electronic waste recycling in Switzerland and in India. *Environmental Impact Assessment Review* 25, 5 (2005), 492–504.

[77] Gary S Sorock, David A Lombardi, Theodore K Courtney, JP Cotnam, and Murray A Mittleman. 2001. Epidemiology of occupational acute traumatic hand injuries: a literature review. *Safety Science* 38, 3 (2001), 241–256.

[78] Suthipong Sthiannopkao and Ming Hung Wong. 2013. Handling e-waste in developed and developing countries: Initiatives, practices, and consequences. *Science of the Total Environment* 463 (2013), 1147–1153.

[79] Anselm Strauss and Juliet M Corbin. 1990. *Basics of qualitative research: Grounded theory procedures and techniques.* Sage Publications, Inc.

[80] Ignaz Strebel. 2018. *Repair Work Ethnographies: Revisiting Breakdown, Relocating Materiality.* Springer.

[81] Lucy A Suchman. 1987. *Plans and situated actions: The problem of human-machine communication.* Cambridge university press. 149–70 pages.

[82] Jennyfer Lawrence Taylor, Dhaval Vyas, and Tony Sharp. 2017. Diversity and coherence in a hackerspace for people from a low socioeconomic community. In *Proceedings of the 29th Australian Conference on Computer-Human Interaction.* ACM, 238–247.

[83] Atsushi Terazono, Shinsuke Murakami, Naoya Abe, Bulent Inanc, Yuichi Moriguchi, Shin-ichi Sakai, Michikazu Kojima, Aya Yoshida, Jinhui Li, Jianxin Yang, et al. 2006. Current status and research on E-waste issues in Asia. *Journal of Material Cycles and Waste Management* 8, 1 (2006), 1–12.

[84] Lucia Terrenghi, Matthias Kranz, Paul Holleis, and Albrecht Schmidt. 2006. A cube to learn: a tangible user interface for the design of a learning appliance. *Personal and Ubiquitous Computing* 10, 2-3 (2006), 153–158.

[85] Brygg Ullmer and Hiroshi Ishii. 1997. The metaDESK: models and prototypes for tangible user interfaces. In *Proceedings of the 10th annual ACM symposium on User interface software and technology.* ACM, 223–232.

[86] Judy Wajcman and Nigel Dodd. 2016. *The Sociology of Speed: Digital, Organizational, and Social Temporalities.* Oxford University Press.

[87] Sushant B Wath, PS Dutt, and Tapan Chakrabarti. 2011. E-waste scenario in India, its management and implications. *Environmental monitoring and assessment* 172, 1-4 (2011), 249–262.

[88] Mark Weiser. 1991. The Computer for the 21 st Century. *Scientific american* 265, 3 (1991), 94–105.

[89] Pierre Wellner. 1991. The DigitalDesk calculator: tangible manipulation on a desk top display. In *Proceedings of the 4th annual ACM symposium on User interface software and technology.* ACM, 27–33.

[90] Rolf Widmer, Heidi Oswald-Krapf, Deepali Sinha-Khetriwal, Max Schnellmann, and Heinz Böni. 2005. Global perspectives on e-waste. *Environmental impact assessment review* 25, 5 (2005), 436–458.

[91] Andrew D Wilson. 2004. TouchLight: an imaging touch screen and display for gesture-based interaction. In *Proceedings of the 6th international conference on Multimodal interfaces.* ACM, 69–76.

[92] Frank R Wilson. 1998. *The hand: How its use shapes the brain, language, and human culture.* Pantheon Books New York.

[93] Frank R Wilson. 1999. *The hand: How its use shapes the brain, language, and human culture.* Vintage.

[94] Raphael Wimmer and Sebastian Boring. 2009. HandSense: discriminating different ways of grasping and holding a tangible user interface. In *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction.* ACM, 359–362.

[95] Susan Wyche, Tawanna R Dillahunt, Nightingale Simiyu, and Sharon Alaka. 2015. If god gives me the chance I will design my own phone: Exploring Mobile Phone Repair and Postcolonial Approaches to Design in Rural Kenya. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing.* ACM, 463–473.

[96] Jinglei Yu, Eric Williams, Meiting Ju, and Yan Yang. 2010. Forecasting global generation of obsolete personal computers.