Patchwork: The Hidden, Human Labor of AI Integration within Essential Work

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This paper examines the rapid introduction of AI and automation technologies within essential industries amid the COVID-19 pandemic. Drawing on participant observation and interviews within two sites of waste labor in the United States, we consider the substantial effort performed by frontline workers who smooth the relationship between robotics and their social and material environment. Over the course of the research, we found workers engaged in continuous acts of calibration, troubleshooting, and repair required to support AI technologies over time. In interrogating these sites, we develop the concept of "patchwork": human labor that occurs in the space between what AI purports to do and what it actually accomplishes. We argue that it is necessary to consider the often-undervalued frontline work that makes up for AI's shortcomings during implementation, particularly as CSCW increasingly turns to discussions of Human-AI collaboration.

CCS Concepts: • **Human-centered computing → Human-computer interaction (HCI)**; **Collaborative and social computing**

Additional Key Words and Phrases: Waste labor, patchwork, AI, automation

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1 INTRODUCTION

In the Spring of 2020, *The New York Times* published a piece entitled, "Robots Welcome to Take Over, as Pandemic Accelerates Automation," in which business reporters Michael Corkery and David Gelles chart a set of Artificially Intelligent (AI) technologies gaining speedy purchase within service sectors [7]. The article observes that social distancing directives and heightened disinfection procedures had begun to prompt more industries to turn to AI-powered robotics, with concerns of virus spread outweighing long-held fears of machines replacing human workers. "[AI and robotics] can be put to frequent use without requiring more paid labor hours, they are always compliant, and some can even provide the data to prove that they have scoured every inch assigned," stated reporter Lisa Prevost in a companion piece on floor cleaning technologies [30]. The excitement around AI technologies circulating in news media at the time coincided with an increase of investment and

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usage across many essential work sectors, from manufacturing to service to waste management [23]. Yet, by July of 2021, the *The Times* was warning of the toll such investments have had on individual job roles and wage inequality more broadly, arguing that pandemic-induced automation may further tip bargaining power toward employers and lead to the widespread displacement of essential workers [5].

In the following paper, we consider what happened in essential work industries during the interim year and half – between the initial buzz around AI and later apprehension. Looking beyond hype and speculation, we investigate the work happening on the ground during deployment of these technologies. Specifically, we examine the rapid uptake of robotics and AI technologies within two critical work sectors associated with managing waste amid the COVID-19 pandemic. Approximately 10% of the tens of millions of people deemed essential workers perform jobs such as cleaning, garbage collection, and sorting recycling (a category we broadly term "waste labor") [45,46]. Janitorial staff at grocery stores, for example, follow stringent guidelines for regularly disinfecting surfaces in order to reduce shoppers' exposure to the virus, as they practice social distancing and manage the stress of working on the front lines of the pandemic. In order to mitigate risks associated with this work, there has been an accelerated push to introduce automatic machines to assess aisle inventory and to aid customer self-checkout. Though intelligent devices have played a role in waste labor industries over the last decade, the pandemic generated a new wave of widespread enthusiasm around the potential for this technology to safeguard both the public and workers from heightened possibilities of contamination. Yet, decades of CSCW and HCI research shows that the introduction of automated technologies into workplaces is not an easy transition; instead, it often transforms and displaces existing work practices [41].

Our research draws on ongoing ethnographic observation in two sites of waste labor that are managing the introduction of AI: (1) an international airport in the Rust Belt region of the United States, piloting a set of autonomous floor care robots and (2) a single stream recycling plant in the Southwest region of the United States, incorporating a new addition to their system of automated sorting machines. We interrogate the accelerated introduction of automated technologies in response to COVID-19, considering how it has impacted the labor carried out by essential workers in these sites.

With these corresponding analyses, first we contribute to the HCI community a comparative case study on how AI has been deployed amid the pandemic in two essential work fields. By detailing how these systems are put to use in daily practice, we highlight the socio-technical work of AI integration in waste labor industries across the US. Second, we offer the concept of "patchwork": human labor that occurs in the space between what AI purports to do and what it actually accomplishes. To show this, we detail the complex acts of integration performed by waste workers as they are tasked with smoothing the relationship between robotics and their organizational, social, and material environments.

The paper that follows examines patchwork in three parts. We begin by reviewing related HCI scholarship about the human work necessary to AI and the vital, yet often overlooked role of maintenance and repair within organizational contexts. We then describe our fieldwork methods and turn to a set of vignettes that explore AI systems at work within essential industries. We end by discussing the wider stakes of patchwork to computer mediated labor beyond sites typically associated with human-AI collaboration or complementarity.

2 RELATED WORK

Our work builds on a rich discourse within the field of CSCW and adjacent scholarly communities on the often-undervalued human work necessary to fill in the gaps of AI in the present, as well as the everyday practices of workers who sustain computational systems.

2.1 The Human Work of AI

For decades, HCI researchers have interrogated how digital technologies shape and are shaped by cultures and practices of work. From airline cockpits to distributed groupware systems, scholars emphasize the importance of supporting a multitude of tasks and creating technologies that integrate into collaborative work settings. Although much of this research is focused on improving emergent workplace technologies, critical scholarship casts an eye on the unrecognized forms of labor that advance technological systems. Brought into the field of HCI through the work of feminist researchers Susan Leigh Star and Lucy Suchman, the theoretical concept of "invisible labor" illuminates how workplace activities or workers themselves may be hidden through obscurity or abstraction [36,41]. In these situations, the products of labor may be visible, but those who perform them remain hidden or reduced to numerical data.

Mary Gray and Siddharth Suri reveal how seemingly automated digital systems rely on the (unseen) human labor of tagging, rating and reviewing border cases—what they call "ghost work" [16]. The term evokes the present, yet invisible, nature of ghost workers. They occupy a "hidden layer" [16] of technology labor that underpins the publicly celebrated, highly rewarded labor of designers and engineers. Lilly Irani observes that this activity occurs within a labor hierarchy in which contact workers don't have access to the same pay or perks as other tech industry employees [18]. Projects such as Andrew Norman Wilson's "Workers Leaving GooglePlex" have captured the tiered systems of technical work, where scanners on Google's large scale book digitization project enter and exit from a separate building on the campus [54]. Their physical task of turning pages in time to a rhythm readable for computer scanning is necessary for realizing the goals of the project [15]. Yet, the contract workers aren't really considered Googlers; revealingly, they wear a red-letter "C" badge that distinguish them from other employees.

This tendency to obscure and devalue the work that technologists rely upon contributes to the mythologization of tech companies — both to the public and to technologists themselves. Such forms of "human computation" are seen as temporary, a form of work that stands in as a stopgap now, but that could eventually be resolved with enough engineering effort [19]. Within data science, for example, the work of gathering and preparing disparate data such that it can be recognizable to a computational system is often characterized as mundane, "janitor work" [18,19], ripe for automation. Even when recognizing the constraints of the present in planning for an automated future, platform companies like Uber or Amazon employ large, outsourced labor forces [50]. As a form of "pre-automation," such firms simultaneously invest in developing technologies to replace these workers with "machines of their own design" [*ibid*]. Certain forms of gig work then lay the infrastructural foundations for future automation.

Rather than thinking at the scale of pre- or post-automation, with this paper, we consider the infrastructural labor workers perform in filling the gaps of AI in the present. With these technologies often in a cyclical process of optimization, workers on the ground regularly smooth obstacles and troubleshoot issues as they arise to keep things going until technologists make their next leap. To put it simply, patchwork is instrumental to AI: in its absence, the entire system would collapse.

In using the term patchwork, we move to highlight what is visible within invisible labor: the material traces that cover the holes in technological systems, keeping them in useable condition *and* preserving how they are perceived. "Patches" have long been a part of computing cultures. Today patches describe minor fixes to bugs in digital code, but in early physical computing, patches were segments of punch cards or tape that were cut out and replaced to update software [29]. The practice resembled patchwork in its original connotation, as an act of mending fabric. This history directly connects our use of the term patchwork to repair. As an analytic lens, repair serves as an intervention into innovation discourses by bringing to light an alternative set of practices and participants often overlooked in dominant narratives of AI [20]. Elsewhere, Rajesh Veeraraghavan uses "patching" to describe top-down, incremental changes to both social and technological systems that facilitate implementation of developmental policy. Though united by an attention to the practices that "make things work as intended," our use of the term is decidedly bottom-up, highlighting the activity of workers rather than bureaucrats [48].

As a form of articulation work, patchwork is especially evident in moments of breakdown [38]. Articulation work is concerned with "getting things back on track" and, when part of larger organizational processes, holds the disparate elements of a system together [36]. Offering the concept of "fauxtomation," documentarian and organizer Astra Taylor describes the sometimes-subtle tuning work that can contribute to the illusion that machines are smarter than they really are [43]. In an illustrative example, Taylor recounts an instance at a restaurant where she observed a patron sharing a sense of amazement that the app he used to place his order sent an alert that his food was ready for pick up 20 minutes early. In response, the cashier carefully corrected him, stating "it was actually me" [*ibid*]. Rather than let the customer's food turn cold, the restaurant worker provided a status update to the app's prediction on the length of time required for preparation, improving the service delivery — a move that fed the customer's faith in the system, until she corrected the narrative.

Importantly, patchwork also upholds public perceptions of AI. In keeping automated systems running, it conceals the shortcoming of the technology and – in doing so – conceals the efforts of essential workers. Automated systems that require the constant input and oversight of adjacent human workers aren't unusual. But they don't fulfill the marketing promises of labor saving and improved accuracy that are tied to total automation. Like ghost work, patchwork, overcomes "the gap between what humans can do and what computers can do" [16]. Patchwork tells us *how* workers overcome that gap – and what they produce in doing so.

We find that patchwork is regularly performed by those closest to the forms of labor approximated by AI — workers whose tasks are offset when automation functions properly and whose roles are shifted when it fails. Over the past several decades Black and Latinx workers increasingly occupy the janitorial and refuse collection workforces [45,47]. At the recycling plant, for example, nearly all the workers observed on the sorting lines were women, most of whom spoke Spanish. In contrast, only 2% of the Silicon Valley technology workforce are Latinx women [25]. By documenting how on-the-ground workers have extended the functionality and performance of AI, we aim to expand considerations of who is responsible for the success of AI systems.

2.2 Maintenance as Vital Organizational Practice

Predictions about the future of work forecast that many workers made redundant by automation will be trained in new roles as the maintainers of automated technologies [55]. AI technologies are said to eliminate the most dull and dangerous tasks in workplaces, improving the satisfaction and safety of workers who are re-skilled into repair roles. Early studies of digital maintenance, such as

Julian Orr's [27] accounts of Xerox technicians, reveal the social nature of this expertise. While from a distance, technicians appeared to repair machines according to their instructions (as was expected), they frequently had to improvise because the instructions were inadequate for many of the unpredictable problems they faced. This both concealed the inadequacy of the instructions and, to a large extent, the insights gained through improvisation. Intuition and interpretation, as Lucy Suchman argues, are essential to executing a plan in practice [39]. Yet, tensions arise when this level of adaptability and situated awareness meets a machine built to follow a pre-ordained plan through systematic routine.

Underlying a focus on the maintenance of automated technologies is a commitment to thinking about design as only one moment within a lifecycle of computational artifacts. Yet, the recurrent focus on knowledge workers (such as engineers and designers) has made it difficult to account for repair work on a broad scale [36]. These concerns are broadened by scholars who highlight larger infrastructural and political conditions necessary to repair technological artifacts [17,20,32]. By studying the integration of automation into essential industries, we surface a new set of labor and technological concerns that emerge after the moment of deployment. In turning to the emergent practices of workers, we also reveal a set of potential solutions produced by workers themselves. This type of analysis concretizes "networks of working relations — including both contests and alliances — that make systems possible" [40:2]. An attention to the maintenance work that sustains new technologies produces needed insight on the multiple forms of labor necessary for implementation.

3 METHODOLODY

"Much of what unfolds in the social world is taken for granted" [4:89], but ethnographic methods allow researchers to observe the actual practices of stakeholders in sites where formative and exploratory knowledge is needed to understand the applications or effectiveness of new technology [9,26]. There is a particularly acute need for these evaluative accounts in times of crisis, when the once routine aspects of daily work change due to evolving health and safety standards set by governmental bodies. Fieldwork is especially well suited for developing a deep understanding of work: both the complex and routine aspects of actions, knowledge, and skill [26,35].

We take a multi-sited approach to the study of two waste labor industries in two locations in the United States—sanitation in the Rust Belt region and recycling in the American Southwest. By studying two sites, we are able to gain broad insight into how automation is introduced and attuned according to the specific contexts of deployment.

Interview data. Due to the "stay at home" orders that characterized the early months of the COVID-19 crisis, this research began with virtual interviews and meetings. Beginning in June 2020, we conducted twenty-two hours of interviews with eleven participants, most of whom were managers and administrative personnel. The questions outlined in our active-interview guides focused conversations on the processes, procedures and impetus for integrating automated technologies in their facilities. This conversational data in the form of interview transcripts provided in-depth information from the perspective of organizational decision-makers.

Ethnographic fieldnotes. In-person access to research sites resumed under IRB approval in September 2020 (Carnegie Mellon University) and February 2021 (University of Texas). When we resumed field research we established pandemic-specific observational protocols, including social distancing, protective equipment, and the keeping of detailed interaction logs should contact tracing be necessary. Our field visits were guided by an attention to the tasks performed by workers, the "pain points" that emerge through their interactions with technology and the solutions enacted by workers and managers to overcome them. We conducted informal conversations with workers throughout our site visits, in both English and Spanish. Data was produced in the form of ethnographic fieldnotes which recorded the everyday work practices of waste laborers and their perspectives on contending with automated machinery on the ground [11]. This field data provided a more complete picture of workplace practices, allowing us to witness activities that occur across our particular sites, even those that may not seem important to participants or worth reporting in formal interviews [10].

Analysis. Interview transcripts and field notes were analyzed using "constant comparative" coding to identify recurring patterns of action [14]. These patterns were then grouped into categories. Each research team determined their categories independently and developed them through a series of reflexive memos based on their field sites [6]. Once we produced categories through site-specific analysis, the research team then compared their analyses to identify points of connection and divergence. In doing so, we sought to build a set of transferable observations informed by our fieldwork that are relevant to other sites of waste labor and sectors negotiating the role of AI in low-wage work.

Analysis of the data from our fieldwork and interviews was also informed by complementary research projects, including an extensive investigation of news reports covering the deployment of AI in our respective industries during the 5-years preceding the Covid-19 pandemic and a set of interviews conducted with engineers, designers and researchers working in the space of service robotics.

In the next section, we offer a brief overview of each field site and their respective relationships to AI, setting the scene for more detailed discussion later on how patchwork came to be crucial to its integration.

4 SITES OF TRANSFORMING OF ESSENTIAL WORK

Shortly after social distancing mandates went into effect in the United States at the beginning of 2020, ***the Airport*** quickly brokered a partnership with Northfield Robotics[1] to pilot the use of ultraviolet (UV) light as a chemical-free means of disinfecting its over half a million, heavily trafficked square feet. Though the core of the facility was built some 70 years ago, a series of renovations punctuated the airport's history over the last half century. An international wing was built in the mid 1960s, followed by the construction of additional gates to accommodate the high demand brought on by an influx of traffic. The airport continued to grow for another decade or so, though traffic steadily declined in the wake of widespread deindustrialization and divestment in the region. With new industries re-entering the region over the last twenty years, the use of the airport has increased and, with it, capital investment — most recently in the form of a new terminal which the airport initially sought to break ground on last year. As COVID-19 hit, construction halted and the airport pivoted their improvement plans to focus on the implementation of several smaller, tech-oriented projects (e.g., machine learning to predict TSA wait times, UV autonomous floor cleaning robots) in collaboration with surrounding industry and academic institutions. Though not as seemingly substantial as a newly built terminal, these efforts align with the company's longer-term strategic aims of becoming a world class, "smart" airport.

Through their partnership, Northfield Robotics has provided the airport with four autonomous UV floor scrubbing robots at no cost. In exchange, Northfield Robotics leverages the expansive and diverse terrain of the airport as a testing site, in order to push early versions of their software or

[1] Names of organizations and individuals have been changed to preserve anonymity.

introduce hardware add-ons for refinement before wide release to the market. Through this arrangement, the airport became one of the first in the field of cargo and airplane travel to apply UV technology in the wake of the COVID-19 pandemic, with associated publicity bolstering its image as an innovative airport.

Though a powerful tool, the UV robots are not able to act on their own, requiring careful calibration and coordination on the part of janitorial staff and airport management. Floors must be cleaned thoroughly before being exposed to light, as dirt and debris impede its ability to remove human pathogens. There are also health hazards associated with UV when in direct contact with human skin, introducing new safety concerns as travel restrictions are lifted. Janitorial staff are essential to the airport's waste labor practices, including overseeing the day-to-day operations of the UV robots, but they are employed by an outside management firm Building Facilities Management (BFM) who hold a longstanding contract with the airport.

The on-site BFM lead manages day-to-day operations, while negotiating the scope of work for janitorial staff across the airport. COVID-19 protocols have continued to reshape essential work and set new standards for cleanliness and disinfection. Staff capacity has also been deeply impacted by a substantial furlough of the vast majority of janitorial staff in March of 2020. Though rehiring has commenced, it is staggered, in ways that apply ongoing pressures to the workforce still there. Our qualitative research focuses on the transformation of essential work at the airport as janitorial staff—unionized, contracted workers—became the primary agents supporting the deployment of four UV floor scrubbing robots across the life cycle of the pandemic.

Reciclo, a Material Recovery Facility (MRF), has used automated sorting equipment in their facilities for more than two decades. Their operation has long relied on technologies like optic sorters, which are powered by basic forms of computation — using light to detect various types of plastic and blasts of air to gather them from waste streams. But, the recycling industry is marked by a new wave of enthusiasm for the next generation of automated sorting equipment which employ cameras, sophisticated algorithms, and robotic arms to recognize, categorize and grab objects off of sorting lines. These AI-sorters were added to Reciclo's facility in 2019, promising granular data and increased accuracy despite working slower than their optic counterparts. MRFs like Reciclo have had to negotiate a tradeoff between human labor, established automated technologies, and robotics that are powered by AI in their attempt to respond to major global changes in the recycling industry, including COVID-19.

Reciclo processes an estimated 16,000 tons of material every month. When material enters the facility on a conveyor belt, it passes through a complex maze of machines and checkpoints staffed by human workers (simply referred to here as "sorters"). The system is a continuous relay between the bulk sorting performed by various machines and moments of refinement performed by sorters. Anything left on the conveyor belt at the end of this process — anything not captured and categorized — is discarded as waste and sent to the landfill. Much of what gets discarded are non-recyclable materials that were either mistakenly or carelessly put into recycling bins and that shouldn't have been in the stream at all. But, inevitably some recyclables are also missed by the machines and sorters. In the words of the General Manager, that's "money left on the table."

The digital "brain" of these robots is powered by computer vision technology that identifies and categorizes objects in waste streams. As material passes underneath the robot on a rapidly moving conveyor belt, a screen lights up with labels. Squares of magenta, orange, and yellow appear over the objects on-screen, each tagged with detailed descriptions like "fiber - carton" or "PET plastic - clear." The robot is capable of recognizing so many different types of objects, but it is programmed to grab only one thing: the high-density and valuable plastic that is used to make milk bottles and laundry detergent containers.

Though the AI robot is smart — providing accurate and granular data about the objects it sees — it struggles physically. Watching the robot for even a few minutes reveals that, on a bad day, its success rate can border near 50%. When a bright orange Tide detergent bottle comes down the line, the robot recognizes it and tags it on-screen. Then the arm engages and makes contact, but comes back empty handed. Minor maintenance was required on the AI-robots nearly every time we've observed the facility and these moments of breakdown became a central focus of our inquiry.

5 FINDINGS: FORMS OF PATCHWORK

In what follows, we trace forms of patchwork across a series of paired vignettes from both sites to tell a story that increasingly builds to inform our understanding of the human labor of AI integration. First, we offer an account of the manual work performed by staff to tend to new robotics technologies and make-up for system failures. Second, we explain how the introduction of AI also introduces additional observational responsibilities for staff, intensifying their work. Next, we observe how many of the breakdowns we witnessed were the result of a misalignment between the physical realities of each location and how AI technologies were originally designed. Finally, we detail how waste workers address these problems by adapting the environment, machinery, and their own practices to accommodate AI deployment, while protecting the quality of their work. With each section, we seek to animate key themes relating to the concept of patchwork through a glimpse into the complex social and material worlds we encountered.

5.1 Ensuring Continued Operation

Waste labor became one of the first lines of defense for the general public as the COVID-19 virus began to spread worldwide. A heightened sensitivity around contamination and surface-spread emerged in the early months of the pandemic, as little was known about how the disease circulates and conflicting recommendations served to heighten fears [44]. All public outlets intensified their sanitation protocols and made efforts to communicate their enhanced practices to their customers. Behind the scenes, stringent cleaning and disposal practices transformed essential work cultures, amplifying existing daily procedures and adding new technologies into the mix in an effort to provide redundancy and assurance. Though lauded for their bravery in the media at the time, frontline workers, of course, shared the same concerns around virus exposure as other members of the public. Yet, by virtue of their sector they were expected to return to work, handling the very surfaces and waste many feared could host viral contaminants.

The efforts of waste workers ensured that the industries supporting daily life continued operation—despite the hurdles and issues that were occurring just beyond public view. Across our field sites, we observed how workers carefully managed the accelerated introduction of automation technologies and treaded new requirements. Within the recycling facility, sorters manually sift through recycling intake when the AI-driven system fails, though managers deem the time automated technologies cannot function as *lost.* Similarly, at the airport, janitorial staff tend to the UV floor scrubbing robots in the event of stall outs and cover the areas that the robots are not able to reach.

5.1.1 Manual Sorting (Reciclo). At the recycling facility field site, upholding the progress of the sorting line requires the agile and adaptive activities of on-the-ground workers. It's clear in these instances just how vital humans are to this socio-technical system. Workers can change their activities to smooth emerging frictions in ways that heavy and permanent machinery simply can't. This is especially true of the facility supervisors. At Reciclo, facility supervisors act in multiple capacities: as overseers (monitoring and troubleshooting the machines), as intermediaries (communicating problems to the maintenance technicians), and as flex sorters (stepping-in to sort at a variety of positions on the line, depending on need). Though they perform some of the same tasks as hourly employees, their role also requires managing a barrage of communicative work. They are responsible for keeping in constant contact with technicians in order to be able to yield to their requests to turn on/off particular machines at specific times; with sorters so they can direct them to do diverse forms of makeshift manual labor; and with management, in order to keep them updated with what's happening in the thick of the facility. This flexibility often requires supervisors to run around back and forth—and be intellectually pulled in every direction—as they have to do urgent connective work.

One particular visit to the recycling field site elucidated the multiple, interlinking nodes of patchwork performed by supervisors when automated technologies fail and produce "downtime." What is revealingly termed "downtime" within the facility's organizational culture actually refers to a moment that is replete with various forms of high-intensity human labor performed in the spatial gaps when machines break down. When we arrived at the facility that morning, everything was uncharacteristically silent and empty. The facility supervisor, Cecilia, explained that the machines had been "down" for nearly 6 hours, due to a software problem with one of the high-tech machines in the facility. Cecelia has a deep, multi-level understanding of operations that are based in experience. Over the 8 years she has been employed at Reciclo, she has worked as a sorter at every station in the facility. She was promoted to head supervisor earlier this year.

The moment of breakdown spurred a chain of events that revealed the varied labor performed by sorters who typically work adjacent to machines. Their coordinated efforts kept the facility going even when the technological system ground to a halt. As Cecelia explained, sorters manually took over the separation of materials—a task that machines are partly responsible for. On this day, and on other days in which there have been sustained periods of downtime, we observed as sorters are beckoned to different downstairs areas of the facility to sort through materials like opaque plastics, or filter out bulky items and plastic wrap. Sorting downstairs is hot and tolling. It requires that sorters perform their duties without the huge fans and conveyor belts that support their task on the platforms. They have to bend down repeatedly to pick things off the floor. In addition, after sustained downtime, management requests that, once up and running again, production lines are run at a faster speed in order to make up for lost time. Sorters are expected to sort faster and through more waste streams that are more contaminated.

In this instance, human workers are performing *compensating patchwork* for the failures of machines, stepping-in to perform their duties. The efforts of frontline workers at Reciclo propelled the organization forward by supplementing technology's shortcomings. When machines couldn't function autonomously, workers were organized to overcome the problem while preserving technology's central role in sorting processes. In the corresponding vignette that follows, we turn to the airport where the introduction of UV floor scrubbing robots extends cleaning practices already heightened amidst the COVID-19 pandemic.

5.1.2 Manual Tending (Airport).

At the airport, safety and sanitation are of utmost importance as travelers from all around move in an out of the space quickly, and with the expectation that the facilities will be kept clean. Turning to a particular scene, shadowing 15-year waste industry veteran Stacey, demonstrates the ways janitorial staff across our observations were called on to compensate for the floor scrubbing robots and how that responsibility drew them in multiple directions.

When Stacey clocks in at 6am, she's assigned a concourse and expected to clean each women's restroom within it at least four times during her shift. She's also responsible for disinfecting departure and arrival gates, as well as surrounding surface areas. Though she is used to being called to periodically address one-off issues that might arise, she tells us radio calls are up since the start of the pandemic. During one particular instance, nearly halfway through her shift, she found herself being split between two radio calls from managerial staff—one asking her to tend to a water spill and the other instructing her to revisit a restroom at a passenger's request.

During our conversation, Stacey reflected on how constraints on her time have made it difficult to meet the caliber of cleanliness expected by her employer (BFM) and airport management. With two the competing requests, she decided to address the one that she felt most immediately compromised public safety: the water. She set her cart with all of her equipment aside and rolled a mop and bucket to where she'd been radioed, about a ten-minute walk from where stood. There she found the puddle next to a stationary UV robot. Though she likened the volume on the floor to that in a drinking glass, she knew any amount water was dangerous to airport travelers, and thus importantly a liability issue for BFM.

After wringing out the excess from her mop, she left the robot to revisit a restroom near the terminal entrance. When she entered, she expected to see some sort of biohazard — a used diaper or tampon. However, she described a nearly barren scene. After scanning a few moments more, she noticed a latex glove on the floor. In the early days of the pandemic, she explained, passengers often wore latex gloves to protect against surface spread. She picked up the glove and threw it into the bin. Finally, she was now able to continue with her assigned route.

Instances like these are now common for Stacey and fellow cleaning staff, underscoring how compensating for the robots' shortcomings affects their daily work. Puddles and trails of waters left by the devices throughout the concourse pose a "slip and fall" hazard for airport passengers, and her priorities must shift to address them. Her anxiety around responding each call in a timely manner is paired with a heightened awareness of contamination, vulnerability, and the need for improved cleanliness. The onus of executing an increasing number of directives weighs heavily on the shoulders of frontline workers like Stacey.

5.2 Intensification and Peripheral Work

Peripheral work—or, work that is tangential to one's assigned tasks, yet takes constant attention—speaks to the omniscient awareness performed by workers who continuously monitor automated technologies. Previously, workers were tasked with simply doing the activities currently assigned to machines. Now, they have the responsibility of maintaining machines, being attuned to their mistakes, and often still doing the original activities. This results in an intensification of their work experience: not only increasing the amount of work they must do, but also changing the shape of that work. Frontline staff at the recycling center might need to stop an assembly line when certain materials combine in order to preserve the physical integrity of the machines. Airport janitorial staff are similarly expected to deviate from their assigned routines to address the needs of the UV floor scrubbing robots, whether they have stalled or sputtered water. This observational labor transforms material work — increasing mental load and conscripting workers into a role of machine-manager.

5.2.1 Simultaneous Oversight (Reciclo). Due to the unsteady performance of automated technologies throughout the facility, sorters are found splitting their attention between the nuances of inventory that run across the conveyor belts and the fluctuating state of the nearby machines. These simultaneous forms of observation bolster the performance of the sorting system, an achievement that is only possible through the *peripheral patchwork* that sorters perform watching over machines. For instance, during a site visit on a summer afternoon we paused to observe the AI robots. While the robot on the left successfully retrieved nearly all of the detergent bottles and milk jugs it identified, the robot on the right failed to grasp them. The computer vision system was working accurately. It identified the correct materials and then engaged both machines. The problem seemed to be at the point of contact: between the bottles and the suction cup that sat at the end of the machine's mechanical, spiderlike arm. When a mustached maintenance technician came to tinker with the right robot's suction cup, we asked how he knew there was a problem. "The ladies told me," he responded (almost all the sorters and supervisors in the facility are women). The ladies, as the technician called them, are a constant source of data regarding the quality of the technology's operation. This observational labor isn't just performed by people in supervisory roles, but every member of the sorting teams.

The central and peripheral focus of the sorters can also be inverted, depending on their duties. Take, for example, the sorter who occasionally occupies the position adjacent to the AI-powered robots when they malfunction. She performs her job duties by looking directly at the machines she is working next to and uses her peripheral vision to pick the materials. When picking at this station, her primary attention is always fixed on the machine to her right. She intently watches to see which objects the machine identifies (and ultimately misses) so she can correct the mistake. She uses her peripheral vision to watch the material stream, rapidly extending her arms a direct, consistent, short distance to retrieve the object herself. In between, she also removes large pieces of cardboard or other cumbersome items that pose a hazard to the continued operation of the line. While the AI robots can only complete a single, highly specific type of task, the sorter can execute and embody "everything else" that keeps the machine running.

5.2.2 In One's Periphery (Airport). Much like at the recycling facility, cleaning staff at the airport perform peripheral patchwork to ensure AI functions as it should. During one field visit, we met with long-time shift supervisor Evan during her break at the food court in the "core" of the airport. The floor scrubbing robots had dramatically changed her work, she explained, such that she was now nearly exclusively focused on overseeing the technology. Evan stressed that the responsibility for the robots' success fell on shift managers like her, and this was fundamentally reshaping their routines. Rather than having the space to check in or offer support to janitorial staff throughout the day, she was tasked with "babysitting the robots."

Put simply, the UV robots are not able to act on their own, requiring careful calibration and coordination. The robots had initially been designed for retail settings, where their small size might be an advantage for maneuvering down narrow aisles or making sharp corners. But in the airport, with its vast and dynamic terrain, cleaning staff need to revisit areas passed by the robot to check for cleanliness and coverage. The tiled floors also present a problem, another supervisor later explained. Across the ticketing and baggage claim areas, there are variable amounts of grout. As the robots move across the floor, water is trapped by each crevice. Janitorial staff must observe nearby and regularly mop up the trail left behind.

As Evan spoke, her eyes quickly darted to the right, where a robot stopped suddenly across from a set of escalators — a red light blinked repeatedly across its screen. As she stood up from the table to troubleshoot the issue, she hypothesized that it had gotten tripped up by a shadow on the floor that it misread as an obstacle (there was no one and nothing passing by at the time). Even on break, she is sure to keep an eye, she told us as she walked away.

These distinct accounts of mounting demands on essential work routines illustrate how labor and automated technology shape one another. Automated technologies introduce new, compounding forms of cognitive labor. The cumulative effect of which can strain the capacities of frontline workers. The belief that AI and automated technologies have the capability to be autonomous renders these changing aspects of essential work invisible. It isn't acknowledged in marketing pitches or training materials, where the role of the worker is inaccurately reduced to "waiting around and attending." Next, we reflect on the cause of many of these problems: discrepancies between robotics and their physical contexts.

5.3 Misalignment between AI and the installation site

Issues in the functionality of AI and automated technologies arise at the point of contact between the machine and its physical environment. Because many automated technologies are programmed to complete a discrete set of tasks under specific conditions, they often lack the ability to handle variability. When the vision for where (and under which conditions) AI technology will perform does not match material realities of its deployment site, it can lead to repeated instances of stall outs or disrepair.

These types of breakdowns can be seen in the MRF, where the sorting technology often ceases to work when faced with incompatible trash. Whether it be wet materials from a rainy day or misplaced plastic bags, the machinery ends up clogged, tangled, and unable to function when it is physically unable to adapt to its shifting environment. The same limitations are observed in the airport's robotic floor cleaning robots, whose scrubbers don't adjust to the variable height of the flooring laid across concourses. The disruption between the vision of AI and its capacities in a given context leaves a void which workers step in to resolve.

5.3.1 Growing Damage (Reciclo). On days when the accuracy of the AI sorting robots is low, a sorter is stationed in the narrow band of space directly next to the pair of sorting robots. The first robot will engage and miss, the second robot will engage and miss, and then the sorter grabs the plastic. This type of patchwork is a basic form of human-robot collaboration, and inspires an almost collegial relationship between the sorters and machines. The sorters who are often stationed nearby know the robot's personalities: one is "better at its job," the sorters tell us. As we watch the machine run, they're right of course. Though these machines are identical in make and model, the first one successfully selects objects more often.

The complexity and variability of waste streams is often cited by technology companies as a key impetus for AI. Recycling needs intelligent machines that can account for and respond to abrupt shifts in material flows. The mechanical technologies that occupy most of the facility are not very adaptable. So, responding to temporary but significant changes — a series of rainy days that weigh down paper or a holiday week that creates an influx in cardboard boxes — is accomplished through a series of small adjustments, orchestrated by management and carried out throughout the system. When damp materials are caught in the hardware for example, one of the frontline workers is repositioned to nudge material through — a form of *collaborating patchwork* that enables the machine to deliver and work towards its intended functionality.

Technologies that respond to variation automatically are possible at a software level. But, in its current state, no amount of machine learning allows the hardware to quickly pivot and modify itself to changing physical circumstances. Here, AI-technologies have the same limitations as their more traditional counterparts. Flexibility remains the purview of the sorter. Three frontline workers underscored this assumption during our observational conversations. Previously, they were stationed in close proximity to one another. However, in recent months, the change in inventory and intake had shifted each person's assignment in the sorting line. They noted that much of their work was animated by anticipation of what may get caught in hardware. Many of their tasks acted as preventative measures in order to avoid damage to the machines. Though the companies that produce AI technologies focus on their potential to increase the safety and security of workers, here it is the manual practices of sorters which preserves the safety of machines.

5.3.2 Managing the Robots (Airport). Airport administrators see the floor cleaning robots as augmenting existing janitorial work, adding additional levels of cleanliness with little need for human oversight. However, to work well, the robots require surfaces cleared of debris and with little foot traffic. Deploying the robots in high density areas, such as the airport during the day, diminishes their capabilities. The automated technology frequently breaks down, either halting in place or jittering in the concourse. This discrepancy causes shift managers and frontline workers to remain on alert as they conduct their daily routines. One supervisor stated that they ultimately had to abandon their normal duties due to concerns on liability, should the machines breakdown in a manner could cause injury to a traveler.

Supervision of the robots involved checking high traffic areas throughout the day. During one particular visit, we saw this on display as a shift supervisor lost track of a robot he had been monitoring. Together we searched the departures floor, behind corners and areas partitioned for construction, but found nothing. It wasn't until a member of the cleaning staff radioed him that we located the robot parked in a niche at the edge of the ticketing area. The supervisor and janitor explained this was such a frequent occurrence that they had asked Northfield representatives to outfit the robots with flag such that they could see it moving from farther away. When that idea didn't move forward, they pushed for the implementation of a text message-based system that would alert them to when and where the robots stall out (at the time of writing, this had not been developed).

Mismatches between AI's digital capabilities and physical capabilities are significant in that they reveal patchwork as a necessary part of technological achievements. Though purportedly faster, more efficient, and more reliable than the human worker, robotics at the observation sites have proven to be dependent on sorters and cleaning staff to ensure completion of their job (e.g., sorters and cleaning staff anticipate breakdown and protect the machines). Media narratives that depict robotics as safeguarding frontline workers overlook the expectations of machine-interference that are a typical part of workers' jobs. Because the environment of essential work often falls out of alignment with the design of technology, collaboration remains necessary to achieve integration within essential work industries.

5.4 Patches

Material reconfigurations of AI technologies, or *patches,* were a distinct artifact of patchwork evident across our sites. Frontline workers developed temporary solutions as an immediate response to infrastructural insufficiencies or technical malfunctions. Rather than a workaround, which might suggest bypassing a problem, patches directly amend the gaps that prevent work from being done. They are the product of workers being highly attuned to the particular make-up of their physical contexts. For instance, at the recycling center, the AI-sorting robots were tossing material too softly to land in the bin where similar plastics were being collected. This resulted in a build-up of valuable material in the corner and crevices of the platform (ultimately resulting in lost revenue for the facility). After identifying the problem, supervisors and sorters began to use an improvised, metal rod to physically push materials into receptor bins so that they could be baled and sold. This simple, material addition quickly improved the performance of the robot in ways that would have otherwise required a reprogramming of the machines' coordinates. Such patches aggregate over time to formulate their own infrastructure, building upon temporary solutions to make permanent design interventions.

5.4.1 Build as It Runs (Reciclo). The conveyor belt is symbolic of regimented productivity and reliability, but the application of patches underscores the creativity that upholds a fragile infrastructure. At the onset of the COVID-19 pandemic, the sudden closure of many office buildings had a measured impact on the flows of recycling at Reciclo. Materials sourced from the local municipality moved from professional settings (which produce relatively clean recyclables, dominated by paper) to mixed residential recycling, as many people began working from home. Leadership at the facility saw this shift as being potentially long-term, and the sorting system was recalibrated to respond to changes in intake. Difference became routine, with the CEO stating, "the new problems of COVID have become normal, so now we're back to focusing on the old problems." Old problems manifested as day-to-day infrastructural shortcomings, with frontline workers developing solutions with swiftness and ingenuity.

The fractured relationship between automated technologies and their environment gradually became visible at the MRF across a series of visits to the facility. Receptacles and improvisational additions to established machinery appeared, transformed, and disappeared over time. These makeshift infrastructures stood in sharp contrast to the enormous machines that dominated the facility whose installation required specialists, data justification, hundreds of thousands of dollars, and several months of planning. Along the conveyor belt on the central platform, supervisors constructed a wall in order to redirect materials that were continuously falling on the floor. This patch unloaded the additional cleaning labor created by the malfunction, a critical issue due to staffing shortages.

The system's dependence on the improvisational infrastructure developed by the sorters underscores the relationship between context, materiality, and automated technology's intended functionality. Patches are site-specific reconfigurations. They're the product of sorters who are attuned local environments in ways that technology designers just aren't.

5.4.2 Disassemble for Continuation (Airport). As the primary operators of the floor scrubbing robots, supervisors were responsible for filling the robots with soap and water, charging their batteries, and cleaning optical cameras. According to staff, the UV floor scrubbing robots malfunctioned frequently due to incompatibility with the physical realities of the airport. One shift manager explained that the machines stall at least once during a single route, and that it'd be considered a good day if a robot got through 25% of its map without getting stuck or needing assistance. As traffic increased alongside the loosening of travel restrictions, they also found the robots at a standstill or making "sudden movements" risking the safety of the people around them. Multiple staff described seeing robots run into people or their luggage. Employees at Northfield Robotics explained simply that people pose a "significant challenge for the operation of the robot," leading to the "kick-outs" and malfunctions the staff observed so often. By the end of our observations, a staff manager told us that "if it's not essential to my job, I don't put them on," which he admitted happened often.

During the later months of observation, we learned that cleaning staff began stripping away some of the UV robots' key features, in order to reduce the liability of stall outs or spills. Attempts to fit the robot into the cleaning staff's routines eventually broke down as underlying problems were never resolved, and airport traffic increased. However, due to expectations around utilizing the robots, janitorial staff and shift managers gradually began to deconstruct the robots' features while preserving its hallmark—the UV light. In our observations, we found that water was no longer being replenished in the robots' tanks and the scrubbers were removed.

Much like the improvised receptacles in the corners of the sorting platform, this deconstruction or disassembly of the floor scrubbing robots represents a patch. In a creative effort meant to make the system work locally, janitorial staff drew on their deep knowledge of the context — spanning both site-specific material constraints and organizational motivations. Patches underscore the fragility of existing infrastructures and challenge marketing claims about the ability of robots to be wholly autonomous. Across both sites, sorters and janitorial staff are integral to the achievements of innovation, as they carry out needed modifications to the design to keep things going.

6 DISCUSSION

Since its establishment, the field of CSCW has examined how workplace collaboration is organized and maintained [33,34,42]. The acceleration of automation and machine learning across formal and informal sites of work has introduced additional layers of complication to these processes, pointing to the increasing role AI technologies play in shaping labor. This observation has led CSCW scholars to expand the field's empirical range to include emerging sites of digital work, from the rise of the "gig economy" [1,21] to the psychological effects of content moderation [31,37], to the extension of managerial oversight brought on by algorithmic management [22,24].

Contributing to this expanding body of scholarship, we have shown how people at the frontlines in essential industries make sense of and manage the technological interventions proposed to heighten or replace aspects of their work. Management and members of engineering firms work together to realize the use of robotics technologies to automate waste work by introducing computer vision to detect particular types of refuse material or to navigate the airport concourse casting disinfecting UV light. If a piece of cardboard lands on the wrong conveyor belt or a trace of containment is found on the surface of the floor, for example, the idea is that the systems will be there to ensure the work of sorting or cleaning is done. However, these visions do not align with the realities of our field sites, where an accelerated push to introduce AI and robotics in response to the pandemic has led to new forms of labor for essential staff—what we term patchwork—requiring increased attention and responsibility. Looking beyond the airport or the recycling facility, we offer patchwork as a concept that foregrounds the human labor that occurs in the space between what AI purports to do and what it actually accomplishes. We close by considering how aspects of patchwork may come to shape CSCW research and practice ahead.

6.1 Necessity of configurational labor

Traditional theories of innovation propose a linear model in which innovation emerges from corporate research and development, is introduced and impelled by marketing, and then ultimately diffuses through industries. Yet, business scholar James Fleck observes that in highly complex organizations — like many essential work sectors — innovation is closer to what he calls "innofusion" [12]. Here, the adoption of new technologies requires an enormous investment of configurational labor, as technologies have to be adapted to particular sites and routines in a way that can't be anticipated prior to installation [13]. Importantly, this kind of configurational labor does not just exist around innovation, but *is* itself innovation. It is only through this work that the use of new technologies becomes feasible.

Across our field sites, we witnessed contributions of configurational labor to the implementation of AI systems — and specifically how the activities of workers smooth the operations of machines that don't live up to the hype surrounding them. Proponents might argue that, like with most newly deployed systems, it's not reasonable to assume AI will work as well when first introduced as they do after time for calibration and refinement. Yet, the work performed by staff to adapt systems far surpassed simple updates or bug fixes. Recycling facility staff formed makeshift infrastructure to redirect materials that were captured by the robots but inaccurately discarded. Janitorial staff at the airport similarly created their own systems to tend to areas that were insufficiently mapped by the robot by placing larger objects in front of slimmer ones. This troubleshooting and improvisation accommodates emerging developments within the real work situations in which the technologies were deployed, and represents the essential implementation/innovation work of AI.

6.2 Redundancy versus surplus

Technology historians Lee Vinsel and Andrew Russell [51] have been careful to separate actual innovation from innovation speak. Innovation speak, or hype, typically comes from a marketing perspective. It's defined by claims of disruption and a discourse of fear, where those who don't adopt technologies will be left behind technologically. These forms of hype were prevalent at the beginning of the pandemic, and by several accounts drove investment in AI across sectors of the economy facing new uncertainty [2,52]. These moves came alongside declarations on the types of employees who were crucial to the functioning of society — essential workers in occupations like healthcare, food production, waste management, among others. While other members of the community stayed home following social mandates, these workers faced threats of viral exposure to ensure that the health and safety of others might be preserved. Yet, the designation "essential" did not necessarily come with a corresponding increase in funds or material support. Instead, at sites like the airport, many staff were furloughed indefinitely as demand for travel stood at historically low levels. Those who remained shifted to a new posture of work — one that required adherence to more rigorous protocols than ever before with fewer resources, and involved the maintenance of new technologies.

In short, the investments made were unevenly distributed. What was thought to last a few weeks or months turned into years, and essential workers are still bearing the undue burden. Though implemented as a means to streamline work, AI technologies at the airport and recycling facility continue to operate alongside essential staff who tend to their shortcomings and regular breakdowns. Even when the pandemic ends, it's unlikely that the tech investments that firms have made will realize their promise. Instead, we are seeing is a gradual abandonment of these technologies at our sights. Though the hype is dissipating there, in wider technology culture we see no corresponding reduction in the impulse to release AI into these real-world settings without adequate training.

Though pundits may extol the promise of AI and robotics technologies to reduce inefficiencies or perpetuate a myth of human obsolescence, such views elide the ongoing human labor necessary to adjust automation technologies to a dynamic world. In situ mapping and localization of autonomous vehicles and robotics, for example, is critical to the technology's navigation of the physical world and ensures the safety of those who might pass alongside them. This requires continuous work. Long after the initial pilot, field operators and technicians must carefully tinker with and calibrate the robots in order to address changes to the physical environment or implement software updates [3]. This configuration work takes both material and social forms. Verdezoto et al highlight how the maintenance practices of frontline workers, in particular, adapt technologies to their cultural and communicative environments [49]. The authors advocate for foregrounding this mediation as a form of contextually-informed systems building. Documenting the labor that attunes technology to the intricacies of the world is a first step in overcoming the obscurity that limits workers ability to guide processes of technology adoption and adaptation, even as they're tasked with handling the problems that arise because of them.

Our responsibility then as CSCW researchers is in conveying not only the promises and limitations of AI in the present, but also to recognize our role in deciding its outcomes and how it might affect labor along a broader timescale. "Upskilling," "job shifting," and other terms used within the future of work discourse suggest a world in which those whose roles have been affected by automation will assume new positions or responsibilities. But what does this shifting actually look like in practice? Within the airport and the recycling facility, it meant experiencing a changing quality of work — often, in the form of intensification. Though deemed a necessary part of implementation, it should be noted that intensification is a social choice [8].

6.3 Good intentions aren't enough

In doing this work, we hope to challenge design narratives that position engineer's intentions as the source of "ethical AI" and that position worker's experiences in the realm of unanticipated consequences. Parvin and Pollock [28] argue that many of the technological impacts that get labeled as "unanticipated consequences" are actually those that were simply unintended by designers, and easily could have been anticipated if design processes included a greater plurality of contributors and perspectives. Good intentions are often thought of as something that designers can code into technological systems. But, as our research demonstrates, so many of the difficulties that workers experience are the product of how technologies are implemented and put to use by decision makers, on site.

Our discussion of patchwork has sought to scrutinize the mismatch in designers' conception of essential work and how it is actually performed. Current automated technologies reflect a lack of consideration for the conditions under which waste workers labor and perpetuate a sense that their work can be left behind. An accurate understanding of who does the work of AI integration begins to dispel a "robotic mystique" that surrounds emergent technologies, or the sense they hold the power of superhuman precision [53]. The way work is seen and measured matters, particularly for frontline workers whose roles are necessary but undervalued [36]. Underlying our focus on the maintenance of automated technologies is a commitment to thinking about design as only one moment within a lifecycle of a computational artifact. Innovative technologies are deeply reliant on the maintainers who keep them running, though this work "remains mostly invisible under our normal modes of picturing and theorizing technology" [20:225]. This invisibility constrains public understanding of whose work matters, and funnels attention and resources away from sustaining the infrastructures and services already central [51].

6 CONCLUSION

In this paper, we have outlined the concept of patchwork to describe the human work necessary to integrate AI within the social and material environments it is intended to augment. Drawing on ethnographic observation in two distinct sites of essential work (recycling sorting and cleaning), we highlight facets of patchwork performed by waste workers managing the introduction of AI and robotics technologies in their workplaces during the COVID-19. Though engineering firms promised that such interventions would enhance existing practices and offer new levels of efficiency, workers took on additional forms of observational, collaborative and compensatory work to accommodate the new machines. Expanding CSCW scholarship on the (in)visibility of work, we argue for more holistic understandings of AI development that both acknowledge these contributions and work to demystify the perceived superhuman precision of AI.

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