ROUTLEDGE COMPANIONS

The Routledge Companion to Ecological Design Thinking

Healthful Ecotopian Visions for Architecture and Urbanism

Edited by Mitra Kanaani

THE ROUTLEDGE COMPANION TO ECOLOGICAL DESIGN THINKING

Healthful Ecotopian Visions for Architecture and Urbanism

Edited by Mitra Kanaani

Routledge
Taylor & Francis Group
NEW YORK AND LONDON

Cover image: Melanie P. Hahn

First published 2023
by Routledge
605 Third Avenue, New York, NY 10158

and by Routledge
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

Routledge is an imprint of the Taylor & Francis Group, an informa business

Library of Congress Cataloging-in-Publication Data
A catalog record for this book has been requested

ISBN: 978-1-032-02389-2 (hbk)
ISBN: 978-1-032-02390-8 (pbk)
ISBN: 978-1-003-18318-1 (ebk)

DOI: 10.4324/9781003183181

Typeset in Bembo
by Apex CoVantage, LLC

3.8

ROBOTS IN THE ROOM, ROBOTS ARE THE ROOM

THE FUTURE OF ROBOTICS, ARCHITECTURAL DESIGN, AND DOMESTIC ROUTINE

Keith Evan Green

What Dwells in a Poet's Bedroom

"I dwell in Possibility," wrote American poet Emily Dickinson.

The poet's dwelling, practically (Figure 3.8.1): a second-floor bedroom in Amherst, Massachusetts, a table, a chair, a bed, a chest of drawers, a lamp. The tiny writing table facing the window onto Main Street is where Dickinson sat and composed 1,800 poems over thirty years. Inside the chest of drawers, after her death, hundreds of poems were found.

The dwelling place: "Possibility." What did Dickinson know of Possibility? An answer is found in the words spoken by the poet to her young niece, from within the bedroom, its door locked with an imaginary key. "Matty, here's freedom" (Rich, 1975). The poet viewed her modest bedroom as a workroom within which she could reflect, imagine, explore, and discover—where she could *make room for herself* in a noisy world. From our distance from Dickinson's bedroom, we might quickly surmise that it was an island apart, a kind of sanctuary, an inside distinct from an outside. But after further contemplation, isn't Dickinson's bedroom instead a portal between her creative life and the universe, continuous and transactional like a Möbius strip? The affirmative is suggested by the poet's words, considered here, which sites the sky *within* her bedroom, not outside its window. Emily Dickinson imagined this Possibility.

Imagine if Dickinson were a poet writing today. It might be absurd to think it, but Dickinson would more than likely have a small laptop on her tiny writing table. The laptop would have a wireless connection to the internet. It wouldn't be unreasonable for Dickinson to have, also, an Amazon Echo or similar AI device on her writing table or, given the table's diminutive size, on top of the chest of drawers. *Alexa, give me another word for 'sweet.'* The hardwood floors of the poet's bedroom, collecting dust and the pet hair shed from her beloved dog, "Carlo," a Newfoundland, would surely benefit from *iRobot's Roomba s9+* vacuum which, as reported by *USA Today* (Chan, 2020), is among the best robot vacuums for collecting such detritus. Dickinson might also be wearing noise-cancelling headphones should Main Street, outside her bedroom window, become heavily trafficked, being so close to the University of Massachusetts Amherst (with its 20,000 undergraduate students), and being a short drive to a *Chipotle*, the popular fast-food restaurant.

Humor aside, the picture of the poet's bedroom, filled with domestic technologies, is more reality than thought experiment. Cyber-physical devices bearing the names of their manufacturers—Apple,

DOI: 10.4324/9781003183181-29

Figure 3.8.1 Inside Emily Dickinson's bedroom: the writing table, on which she wrote 1,800 poems over thirty years, is aligned with the bedroom window overlooking Main Street.

Source: Photo courtesy of the Emily Dickinson Museum.

Amazon, Google, iRobot—have come home with us in countless numbers. We invite them to enter and occupy our rooms. Out of the box, they draw and expend energy, with a mission. They are black and white and silver cylinders, sentinels, sitting on our kitchen counters, on our home-office desks, listening for us, and making their own way across our floors with little of our oversight.

In the literary imagination, in research laboratories, and increasingly from the marketplace, humanoid robots—robots that look and behave more like us—are also coming home. What do humanoid robots find when they arrive there? Consider Klara of Kazuo Ishiguro's novel, *Klara and the Sun* (2021), a highly intelligent humanoid robot capable of calculating the age of Josie, her human recipient, as 13.5 years old. Despite making this calculation with precision, Klara, entering Josie's home for the first time, meets the unexpected: the home's furnishings and household items are not consistently and customarily returned to the same location as they had been by the manager of the retail store—Klara's first home.

> The kitchen was especially difficult to navigate because so many of its elements would change their relationship to one another moment by moment. I now appreciated how in the store—surely out of consideration for us [robots]—Manager had carefully kept all the items . . . in their correct places.
>
> *(Ishiguro, 2021)*

The act of precisely fixing the locations of furniture in a room is not only found in fiction: in the Barcelona Pavilion and the Tugendhat House, architect Mies van der Rohe fixed the furniture to the floor in accordance with his design concept for the interior (Jefferson, 2011). Notoriously, Frank Lloyd Wright would show up unexpectedly at his clients' homes to reposition the furniture according to his, as he put it, "original scheme, considering the whole as an integral unit" (1908). Ishiguro's "Manager" and the two architects, Mies and Wright, were intent on providing inhabitants (sometimes robots) with a clear mental map of where things belong in a room. The opposite of this strict spatial organization can be found, curiously, in another well-known work by Mies, Crown Hall of the Illinois Institute of Technology, which has an open plan across which furnishings can be arranged by inhabitants following their needs and whims, much like the kitchens Klara finds herself in at her new homes. To navigate such "unstructured environments," robots make a mental map of their organization that can be updated in real time with reasonable accuracy. Unlike the well-managed sales floor, however, the unstructured domestic landscape, due to its moving parts of people, pets, and household things, can be more challenging for a robot to make sense of. Klara might find Dickinson's bedroom of few furnishings relatively ordered. Or, somedays, maybe not.

In any case, a robot of Klara's intelligence is the invention of a novelist's imagination and not yet a reality. Ishiguro's Klara (she?) has much in common with another robot imagined by a novelist, "Adam," of Ian McEwin's contemporaneous novel, *Machines Like Me* (2019). As narrated by Adam's owner, Charlie Friend, "Adam has . . . a human nature—and a personality" (McEwan, 2019). A robot of Adam's intelligence, embodying a human nature and personality, arguably may never come into existence (Horgan, 2020). But robots today are more and more capable of walking and talking "naturally," conveying and recognizing human emotion, drawing and singing, and performing surgeries with human oversight (Merkusheva, 2020). No fantasy, humanoid robots are expected to occupy our homes, workplaces, schools, and hospitals in surprising numbers. In fact, the "Global Humanoid Robot Market" is expected to reach $13 billion (USD) by 2026 (Merkusheva, 2020).

The Window Exposes a Limit

The bedroom window was a feature that Emily Dickinson privileged in structuring her domestic workspace. The center of the window was the anchor for locating her tiny writing table. Klara similarly structured her existence around windows, by necessity: the light of the sun coming through windows serves as her energy source.

Upstairs from the kitchen in Klara's new home, Josie's bedroom was, for Klara, "just as Josie promised"; it featured a "bedroom rear window" that "had a clear view across the fields all the way to the horizon, allowing us to watch the Sun sinking" (Ishiguro, 2021). As Klara observes, the sky from this bedroom window was "far larger than the gap of the sky at the store" (that previous home to the robot) and "capable of surprising variations. Sometimes it was the color of the lemons in the fruit bowl, then could turn to the gray of the slate chopping boards" (Ishiguro, 2021). Are these mental mechanizations of a robot mere observations, or poetry, or both?

Emily Dickinson referenced the sky in several of her poems. In one, Dickinson referenced the sky aiming to convince her brother to return home, to Amherst, to the family home: "There is another sky / Ever serene and fair / . . . Prithee, my brother, / Into my garden come!" Here, the sought-after sky is found not outside her bedroom window but from within it, from inside the family home, her "garden" (Dickinson, 1960b). In another poem, Dickinson remarked how the immeasurable sky can fit "with ease" into that remarkably compact organ responsible for higher-order, human intelligence, "The Brain," which she argues "is wider than the Sky—/For—put them side by side—/The one the other will contain/With ease—and you—beside—" (Dickinson, 1960a).

Dickinson discovers the sky in a room and in the mind; whereas Klara sees a sky and matches this recognition to other objects in her data base. In the *New Yorker* (January 7, 2020), Dan Rockmore tackles the question, *What distinguishes the poetry of the poet and the robot?* Rockmore characterizes the poetry of an Artificial Intelligence (A.I.) as being, as I just inferred, "poetry as collage" more than "true composition." In a Turing Test of poetry (that Rockmore helped organize), where literary judges assessed whether poems generated by intelligent machines and human poets were distinguishable, not one work by an A.I. fooled the judges—no matter how "deep" the A.I's neural network (Rockmore, 2020). Which is to say, there was something miraculous that Emily Dickinson did in her bedroom that no robot is capable of.

The Robot Is the Room

Any time soon (for sure), we won't expect to find a "Klara" before our bedroom window, composing poetry that attains human achievement in the same. But we most certainly can find a human poet in a room, finding convenience in machines—a laptop or an Amazon Echo, a robot vacuum, noise-canceling headphones. And it might not be long before a humanoid robot can perform for the poet low-level domestic tasks that would free the poet to dedicate more time to writing poetry. That would be a great gift of technology to the poet and to all of us.

Granted, intelligent machines will not attain the poetry of human poets; but might intelligent machines do something more for us than vacuum pet hair from our floors and respond to our simple-minded questions (*Alexa, give me another word for 'sweet.'*)? What do intelligent machines and, more specifically, domestic robots of the near future offer us? What's next?

Many designers of these machines will persist on the pathway to developing a humanoid robot that matches or exceeds human faculties such as imagination, intuition, and will. But for those designers who do not envision nor embrace the arrival of that future, robots will arrive in other forms and sizes that exhibit behaviors that are, rather than human, inspired by other living things or are altogether artificial. For one, we can view the bedrooms and kitchens inhabited by Emily Dickinson and Klara as *already machines*, just as did architect Le Corbusier, who asserted the same in his oft-quoted adage (Le Corbusier, 1986), "*Une maison est une machine-à-habiter*" ("A house is a machine for living in"). Some fifty years later, at M.I.T. (the Massachusetts Institute of Technology), architect and computer scientist Nicholas Negroponte established the foundations for "intelligent environments" (Negroponte, 1975), his M.I.T. colleague William Mitchell subsequently envisioned "robots for living in" (Mitchell, 1999), and former *Wired* editor Kevin Kelly meanwhile imagined an "ecology" of smart "rooms stuffed with co-evolutionary furniture" (Kelly, 1994).

Inspired by this trajectory, and with faculty and student collaborators from many fields, I have been working for two decades at the interface of architecture, robotics, and psychology on what I call "architectural robotics"—cyber-physical environments that support and augment us at work, school, and home, as we roam, interconnect, and age (Green, 2016). In architectural robotics, computation is embedded in the physical fabric of the built environment. In my work, architectural robotics is manifested mostly at room-scale so that, rather than proliferating robots in the room, I recognize that *robots are the room*—a robot-room.

Accordingly, a robot-room, given its spatiality, represents a different kind of human-computer or human-machine interaction when compared to an object-scaled device like a Roomba vacuum or an Amazon Echo. Rooms are all around us, contain us, challenge our physical scale; whereas with smart phones, laptops, and other small devices, we have a commandeering relationship: we interact with them with our hands and sometimes place them in our pockets. This is why the Viennese architect Adolf Loos discouraged the photographing of his architectural works: a photograph could not possibly capture their essence when that essence escapes us at every vantage (Green, 2016).

A robot-room is also something more than a conventional room as we know it. A robot-room physically reconfigures itself to support and augment us. This physical reconfiguration may come as the result of us pushing a button or vocally commanding the room to change form or may come as the result of us gesturing it, or it may come as the result of it knowing something about us and our surroundings to anticipate our needs. In my lab, we are mindful to plan the trajectory of moving components in a manner that is easily understandable to inhabitants of the room (tracing the way, for instance, that living things move) and must be compliant rather than rigid (as to not be perceived as or indeed be threatening). A robot-room may also have, integral to it, not only moving components but also information technologies such as (very likely) sensors as well as programmable lighting, audio, and computer displays.

The physicality, behavior, and affordances of architectural robotics promise to make robot-rooms an intimate stage for our domestic routines. Given the intimacy of this relationship, what must we demand of robot-rooms and what do we desire of them?

We understand what robots do well (or are expected to do well in the near future), so we might expect the same of robot-rooms: they can handle our tedium—monotonous, mundane, and sometimes dangerous tasks; they have unwavering focus and follow-through; they can deliver to us the vast amounts of information available to them and have perfect recall of what they've been fed; and they have become very good at analyzing the information they have collected about where they are and what's happening around them, which informs their responses, their actions (Cobalt Robotics, 2018). We also know what robots do poorly, so we should expect no better from a robot-room: they are not empathetic; they are not (yet) quick learners—the unexpected remains a problem for them; and we do not easily accept or trust them—yet (Cobalt Robotics, 2018).

My research lab group, the *Architectural Robotics Lab* at Cornell University, strives to exploit these numerous virtues and shortcomings of robots in designing robot-rooms. What follows here is a review of some of the most recent design research activity in my lab since the publication of my book *Architectural Robotics: Ecosystems of Bits, Bytes and Biology* (2016), with a focus, in each robot-room case, of a virtue we tried to exploit or a shortcoming we tried to overcome. In the process of designing robot-rooms, we have learned a lot about this emerging category of robot, we have learned something new about the future of designing rooms, and we have also learned something about our own behavior—about what it means to be human as we come to live, play, and work with robots and, here, in robot-rooms.

Lending a Hand

In 2020, *iRobot* reported that more than 30 million home robots have been sold to date (iRobot, 2021). But what might be the next robot that enters our homes in large numbers? My research lab sought an answer in SORT (Figure 3.8.2) that, like a Roomba, is a cylindrical robot of "appliance" size, only ours walks across walls, not floors.

Why this? In bedrooms, in kitchens, throughout our homes, workplaces, and schools, we rely on horizontal surfaces such as counter tops, desktops, cabinets, and shelves for organizing and storing our belongings. Maintaining an organized lifestyle is an important daily routine that reduces negative mental and physical effects caused by cluttering. When poorly managed, domestic items can be difficult to find, causing frustration and cluttering which negatively impact our physical and mental wellbeing. Manifestations of this negative impact include a reduction in working memory, an increase in stress, and difficulty in object identification. A messy environment can be especially challenging to manage for people with various forms of impairment including as elderly people with mild cognitive impairment, patients recovering at home needing medication management, and individuals on the autism spectrum.

Supporting, especially, these three user groups and with application to the broader population, SORT ("Self-Organizing Robot Team") is a multi-agent system of wall climbing robots for supporting independent living by helping users organize domestic items on walls. SORT suggests how assistive technologies leverage our everyday physical environments to perform functional tasks and provide mental support towards improving users' wellbeing.

My lab group studied how people responded to an early SORT prototype (Zhang et al., in Press). To accomplish this objective, we asked participants to rate, on a Likert scale, the extent to which they agree with statements such as, "*I think I would like to use SORT*," "*I think it is helpful that SORT*

Figure 3.8.2 SORT, delivering a medication bottle to a user at a scheduled time and offering nonverbal reminders.

Source: Image courtesy of the author.

can move and transport, fetch and deliver things to me," and "I think it is helpful that SORT can remind me of tasks." We found roughly 80% were favorable to SORT, which suggests the promise of these little robots being invited into the rooms of our homes and, we hope, improving life quality there.

Establishing Trust

When at home or work or in school, human beings are accustomed to things not autonomously moving. Robot vacuum cleaners, however, have paved the way for having at home "agents"—things that are interactive and have a little agenda of their own. Whether or not Roombas or SORTs will prove welcomed additions to our homes over the longer run will rely on whether people can trust them.

In a study to investigate whether a robot and a human being in the same room could establish a trusting relationship, my research group developed a robotic table that, at rest, disappears into the wall and, when activated, gently bends itself to form a writing surface (Figure 3.8.3). Our intention here was to design and build a robot that "was the room," not a robot that was added to a room. Our writing table disappeared into the wall, emerging when it imagines you need it. Maybe if Emily Dickinson were spending a semester as visiting fellow of Harvard University in Cambridge, Massachusetts, where apartment rents are exorbitant, a writing table like ours might prove useful. If she could trust it.

In our study (Wang et al., 2020), in a small room containing only our wall-embedded robot table and a chair, participants were asked to copy a short paragraph on standard letter-sized paper. Given this task, a participant might expect us to furnish the room with a table or some other suitable writing surface; however, none is offered them. That is, until the embedded robotic surface provides one. While in motion, bending downward, the robotic surface pauses, permitting the user to recognize its rigid, planer surface as suited to the task. A participant curious enough might consider the robot's affordance and inspect it further (Figure 3.8.3). If the curious participant moves closer, the robot surface adjusts its position subtly as a cue and gently rests itself on the participant's lap to provide a writing surface. In this scenario, in which a trust was established, the participant copies the paragraph easily with the aid of the drawing surface; and when the task is completed, the robot surface rises on its own, allowing the participant to stand and leave the room.

Figure 3.8.3 A robot surface for writing: still images taken from the video of the lab study. (Consent was collected from participants to publish their likeness as per Cornell University IRB approval.)

Source: Image courtesy of the author.

This "trusting" scenario is what we hope for. But there is another scenario where the participant, ignoring or rejecting the table altogether, completes the task of copying by using the room's wall as a writing surface. In fact, in our lab experiment involving 11 participants, we observed 6 participants using the robot surface as a writing surface, 4 participants using the room's walls or windows as writing surfaces, and 1 participant using his lap. We planned on continuing the same study with more participants, but the study was terminated due to stay-at-home orders during the pandemic. To compensate, we moved the same protocol online, using video recordings, conducting a study with 120 participants. Results strongly suggested that people perceived our robot surface as establishing a trusting relationship whereby the robot was perceived as *intelligent*, *cooperative*, *collaborative*, *friendly*, and *welcoming*. Perhaps we'd be willing to dwell in a robot-room that expands a conventional room's possibilities if rental and home ownership costs continue to increase while living spaces shrink to accommodate all of us.

Working Together

We've considered how three humans—Mies, Wright, and Ishiguro's Manager—were intent on structuring the furnishings of a room according to their own designs, and the difficulties robots like Klara have navigating kitchens that tend to be far less structured. Our lab was interested in studying the inverse, whereby the robot takes on the task of organizing the room. More specifically, we wanted to see if a child would collaborate with a robot in a room-structuring task and, moreover, whether a child might come to the rescue of the collaborating robot if the robot made mistakes that were obvious to the child. This is not so much the case of a robot-room but more the case of a robot assuming the role of the room's designer.

In our lab study (Kocher et al., 2020), we developed a simple, non-humanoid, cubic-shaped robot we call "Chirp." We asked 3–7-year-old children, one at a time, to work with Chirp to build a fence around sheep to keep the sheep from escaping the farm. The components of the fence were infant play-yard fences we mounted on casters so that they can be pushed easily across the floor by Chirp or a child; the sheep were small black-and-white cubes that sat on and could easily be moved across a floor. Also on the floor was a bin that served as an obstacle. But when the fencing task was about half-way done, Chirp ran unexpectedly into the obstacle, clearly needing help from the child. We observed whether that child came to the aid of the robot and, if aid was offered the robot, how long it took the child to offer it. We found that 59% of the 22 young participants came to the aid of the robot and that, among those children who helped the robot, the time it took before help was offered ranged from 6.3 to 43 seconds. In the group of 3–7-year-olds, the younger children were more likely than the older children to correct the problem by moving the robot. All older children who elected to help the robot did so by removing the obstacle. Our findings suggest that children will help a robot, even when the robot looks nothing like a human or a pet or some other familiar living thing. It seems that "helping behavior" is exhibited, even by the youngest of us, even when we encounter small, error-prone robots in our rooms.

Helping Kids Read Books

It was reassuring to learn that, if robots fail to function as intended, a human being, even the youngest of them, would likely help it. But what kind of robot-room might help a child who needs help, say, reading? Illiteracy is an enormous problem in the world. Roughly 20% of the world's population is illiterate (UNESCO, n.d.), and 50% of U.S. adults can't read a book at an eighth-grade level (OCED, n.d.). With such disheartening illiteracy rates, public libraries in the U.S. have intensified efforts to cultivate literacy skills. At public libraries, however, digital technologies for cultivating literacy have mostly materialized as public-access computers loaded with software, supported by

Figure 3.8.4 LIT ROOM: Left—a researcher introducing the LIT ROOM to young readers; Right—a read aloud session conducted by a librarian. (Consent was collected from participants to publish their likeness as per Cornell University IRB approval.)

Source: Image courtesy of the author.

library staff. But interacting with a "keyboard-mouse-screen" does not offer the immediacy of interacting with the printed page, and both forms of interaction are far removed from the physical, tangible, social world that young children thrive in. The divide between the digital and physical worlds leaves all of us "torn between these parallel but disjointed spaces" (Ishii and Ullmer, 1997). How to bridge the digital-physical divide to cultivate literacy in children?

As a response, my lab group developed the "LIT ROOM," an evocative, literacy support tool at room-scale (Figure 3.8.4) embedded in a public library. This physical-digital environment is transformed by words read by its young visitors so that the everyday space of the library "merges" with the imaginary space of the book: *The book is a room*. And should the LIT ROOM's intelligent reconfigurations not match the imagined spaces of young readers, the young readers "fine-tune" the room through tangible interfaces for a second reading of the book. For over a year at the Richland Library, the largest public library in South Carolina, the LIT ROOM served young students from public schools receiving "Title I" support (U.S. Department of Education).

From surveys and interviews with 36 children and 6 school librarians (Schafer et al., 2018), we found evidence that our cyber-physical LIT KIT enhances children's picture book reading, both during and after interactive read-alouds, creating a multi-media, mixed-reality experience that transforms everyday environments into an environment evocative of the picture book being read.

Finding Balance

Prompted by climate change, a growing population, rapid urbanization, global pandemics, and limited access to nature, there is an urgent need to rethink the design of domestic settings. Humans are spending considerably less time outdoors and reside increasingly in crowded urban areas. Looking to the future, we are preparing for the possibility of living in extreme environments on Earth and other planets. Such homes may be spatially confined: capsule habitats like submarines or spacecrafts or microhomes and offices of less than 200 square feet located in rapidly developing geographic locations where the price and/or availability of land is prohibitive. Evidence shows that confined spaces can stress inhabitants; they separate us from nature and cause social isolation which negatively impacts emotional wellbeing (and, in very rare cases like Emily Dickinson's, results in great art). To prevent the spread of infectious disease, the stay-at-home measures of the COVID pandemic further compel the need to find ways to sustain mental health during long periods isolated in tight confines.

Embedding ecologically rich, interactive, biofeedback interfaces into domestic architecture may enrich the experience of living in confined, isolated rooms. Accordingly, my lab group is developing "pheB," a "plant-human, embodied, biofeedback" robot surface aiming to support the wellbeing of human inhabitants in small rooms (Figure 3.8.5). This bio-cyber-physical surface aims to provide inhabitants with therapeutic support manifested as gentle, responsive behaviors of the soft robot, shaped by computational transformations of electrical signals emitted by plants and humans (who care for the plants). This robotic interface is designed to increase the inhabitant's ability to regulate emotions through biofeedback, whereby the robot behavior and physiological states of the plant-human dyad synchronize (Sabinson, 2021).

Emily Dickinson spent long hours for most of her life in her bedroom. Mindful that diagnosing the mental condition of a deceased person is highly speculative, a psychological study (Vedantam, 2001) suggests that Emily Dickinson had mood swings of depression and mania that varied with the amount of sunlight available to her in her room, a disorder we know now as "Seasonal Affective

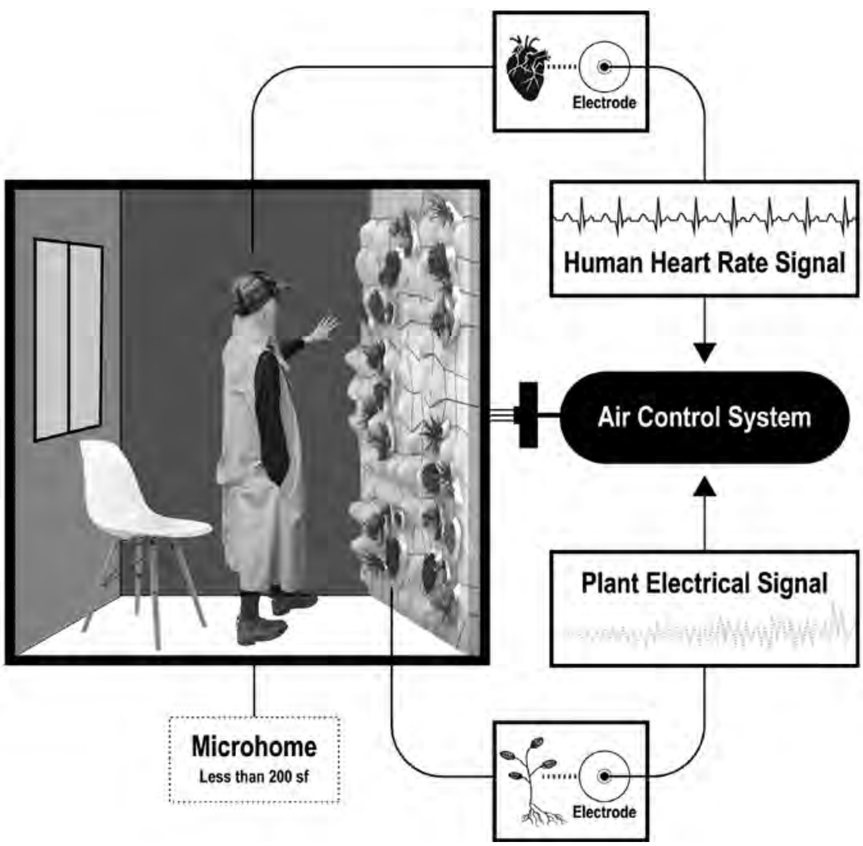

Figure 3.8.5 pheB, a soft robotic biofeedback surface: rendering of a microhome interior showing an inhabitant interacting with pheB.

Source: Image courtesy of the author.

Disorder," or SAD. If, outside Dickinson's bedroom window, the chestnut street was in bloom, then the sky of her poem was blooming and she, "Inebriate of Air." Ishiguro's Klara is also dependent on the sun to nourish her; the functioning of human and robot demanded a bedroom bathed in natural light.

However indispensable sunlight is for bedrooms, this chapter suggests that designers of homes and robots can do more for rooms than invite natural light into them or vacuum their floors or, one day in the future perhaps, create for us reliable, human-looking robotic butlers. Rooms can moreover be embedded with robotics that climb walls to organize our lives and provide us things or emerge from walls as tables when we are inspired to write something, or conjure atmospheres conveyed by picture books to help the youngest of us read, or serve as a homeostatic interface between our inner emotions and the physical world. And people, even 3-year-olds, can recognize these rooms as collaborators and come to their aid if the robot fails to function as expected or desired.

As was argued early in this chapter, rooms are not islands. The people in them and the rooms themselves change over the life of the inhabitant and over the course of human existence. A cave became a palace and a control room and an operating theater and a space craft and, for long stretches of time during the pandemic, a cell for everything. And shaped by all the previous rooms, by what we can design and engineer, and by whatever we might face on this planet, the next iteration of the room—what I call a *roomworld*—will become increasingly, to borrow the words of computer scientist Seymour Papert, "an object-to-think with" (Papert, 1980), a cognitive environment, the connective tissue that fuses our human "being" and the universe, the locus by which we envision a better world, room by room.

Acknowledgments

The design research of my lab could not be realized without my awesome student and faculty collaborators. I'm especially thankful to my Ph.D. students for their efforts in leading the endeavor noted here: Mengni Zhang (SORT), Yixiao Wang (robot surfaces); Deanna Kocher (child-robot interaction), George Schafer (LIT ROOM), and Elena Sabinson (pheB); their first-authored papers are cited here, and Figures 3.8.2–5 are images generated by or with them.

References

Cobalt Robotics. (September 24, 2018). 5 things robots do better than humans (and 3 things they don't). *The Robot Report*, retrieved August 19, 2021, from: www.therobotreport.com/5-things-robots-better-humans/.

Chan, J. (December 11, 2020). The best robot vacuums for pet hair of 2020. *USA Today*, retrieved August 16, 2021, from: www.usatoday.com/story/tech/reviewedcom/2019/10/16/best-robot-vacuums-pet-hair-2019-neato-irobot-roomba-more/3995692002/.

Dickinson, E. (1960a). The brain is wider than the sky, in *The Complete Poems of Emily Dickinson*. Boston: Little Brown. Available from Bartleby.com, 2000, retrieved August 17, 2021, from www.bartleby.com/113/.

Dickinson, E. (1960b). There is another sky, in *The Complete Poems of Emily Dickinson*. Boston: Little Brown. Bartleby.com, 2000, retrieved August 17, 2021, from: www.bartleby.com/113/.

Green, K. E. (2016). *Architectural Robotics: Ecosystems of Bits, Bytes, and Biology*. Cambridge, MA: MIT Press.

Horgan, J. (December 4, 2020). Will artificial intelligence ever live up to its hype? *Scientific American*, retrieved August 17, 2021, from: www.scientificamerican.com/article/will-artificial-intelligence-ever-live-up-to-its-hype/.

iRobot. History, retrieved August 23, 2021, from: www.irobot.com/about-irobot/company-information/history.

Ishiguro, K. (2021). *Klara and the Sun*. New York: Knopf, pp. 49, 54.

Ishii, H., and Ullmer, B. (1997). Tangible bits: Towards seamless interfaces between people, bits and atoms. *Proceedings of the Conference on Human Computer Interaction* [CHI 97], pp. 234–251.

Jefferson, M. (July 18, 2011). Barcelona chair deconstructed, retrieved August 19, 2021, from: https://designapplause.com/design/home/home-office/barcelona-chair-deconstructed-wright/15779/.

Kelly, K. (1994). *Out of Control: The Rise of Neo-Biological Civilization*. Reading, MA: Addison-Wesley.

Kocher, D., Kushnir, T., and Green, K. E. (2020). Better Together: Young children's tendencies to help a non-humanoid robot collaborator. *Proceedings of IDC 2020: The International ACM Conference on Interaction Design and Children*, pp. 243–249.

Le Corbusier. (1986). *Towards a New Architecture*. Transl. F. Etchells. New York: Dover.

McEwan, I. (2019). *Machines Like Me*. New York: Nan A. Telese, Doubleday, pp. 24, 27.

Merkusheva, D. (March 25, 2020). 10 humanoid robots of 2020. *The American Society of Mechanical Engineers*, retrieved August 17, 2021, from: www.asme.org/topics-resources/content/10-humanoid-robots-of-2020.

Mitchell, W. J. (1999). *E-Topia: Urban Life, Jim—but Not as We Know It*. Cambridge, MA: MIT Press.

Negroponte, N. (1975). *Soft Architecture Machines*. Cambridge, MA: MIT Press.

OCED. (n.d.) (The Organization for Economic Cooperation and Development), retrieved August 20, 2021, from: www.oecd.org/unitedstates/.

Papert, S. (1980). *Mindstorms: Children, Computers, and Powerful Ideas*. New York: Basic Books.

Rich, A. (1975). Vesuvius at home: The power of Emily Dickinson, in *On Lies, Secrets, and Silence: Selected Prose By Adrienne Rich*. New York: W.W. Norton, pp. 157–183.

Rockmore, D. (January 7, 2020). What happens when machines learn to write poetry. *The New Yorker*, retrieved August 17, 2021, from: www.newyorker.com/culture/annals-of-inquiry/the-mechanical-muse.

Sabinson, E., Pradham, I., and Green, K. E. (2021). Plant-human embodied biofeedback (pheB): A soft robotic surface for emotion regulation in confined physical space. *Proceedings of TEI 2021, the Fifteenth International Conference on Tangible, Embedded, and Embodied Interactions*, Article no. 89, pp. 1–14.

Schafer, G., Green, K. E., Walker, I. D., and Fullerton, S. K. (2018). Words become worlds: The LIT ROOM, a literacy support tool at room-scale. *Proceedings of the 2018 Designing Interactive Systems Conference* (DIS '18), pp. 511–522.

UNESCO. (n.d.). The global literacy challenge, retrieved August 20, 2021, from: *unesdoc.unesco.org/images/0016/*001631/163170e.pdf.

U.S. Department of education. Title I, retrieved August 20, 2021, from: https://www2.ed.gov/programs/title iparta/index.html.

Vedantam, S. (May 16, 2001). Dickinson may have had bipolar traits. *Los Angeles Time*, retrieved August 23, 2021.

Wang, Y., Guimbretière, F., and Green, K. E. (2020). Are space-making robots, agents? Investigations on user perception of an embedded robotic surface. *Proceeding of the 2020 29th IEEE International Conference on Robot and Human Interactive Communication* (RO-MAN 2020), pp. 1230–1235.

Wright, F. L. (March 1908). In the cause of architecture. *Architecture Record*, pp. 155–165.

Zhang, M., Hardin, J., Cai, J., Brooks, J. O., and Green, K. E. (In Press). Self-organizing robot team (SORT): A multi-robot, wall climbing organizer-and-delivery system for living spaces, in *Adaptive Environments Book Series*. New York: Springer.