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CHAPTER 5

The Convivial ART of *Vortical* Thinking

Keith Evan Green

Ask a young child to draw a robot, and (almost without exception) he or she responds by delineating with pencil or crayon a humanoid robot – symmetrical, boxy and awkward, part us, part machine. Indeed, this representation of robotics is the one that most adults maintain: robotics defined by anthropomorphism, most manifested as humanoid robots. It follows that a robot intended to care for you is presumed to be, again, a humanoid-robotic servant, or maybe a friendly, animal-like robotic companion, such as a furry white seal or a plush teddy bear. This presumption comes partly from media – the many humanoid robots featured in movies, television shows and comic strips – and partly from that ancestor of the humanoid robot, the robot before electricity. Indeed, one third of Lisa Nocks's history of robotics, *The Robot: The Life Story of a Technology*,[1] is devoted to such mechanical contrivances resembling human beings and animals – the precursors of electronic offspring that, for Nocks, is almost exclusively that artificial breed recognisable as the humanoid robot.

Without face or fur, with no or few words, behaving in a manner that is only vaguely familiar to us, an altogether different kind of caring robotics is being realised within my Architectural Robotics Lab (Cornell University, New York, USA) and in situ within the Roger C. Peace Rehabilitation Hospital (Greenville Hospital System University Medical Center, South Carolina, USA). Very much a continuing project undertaken by this partnership, *home+* (Fig. 16) is a suite of networked, distributed robotic furnishings integrated into existing domestic environments (for ageing in place) and healthcare facilities (for clinical care). *home+* is our reply to the question, How can our everyday environments be outfitted with assistive robotics promoting independent living?

A response to this question, coming from my trans-disciplinary design research team representing Architecture, Human Factors Psychology,

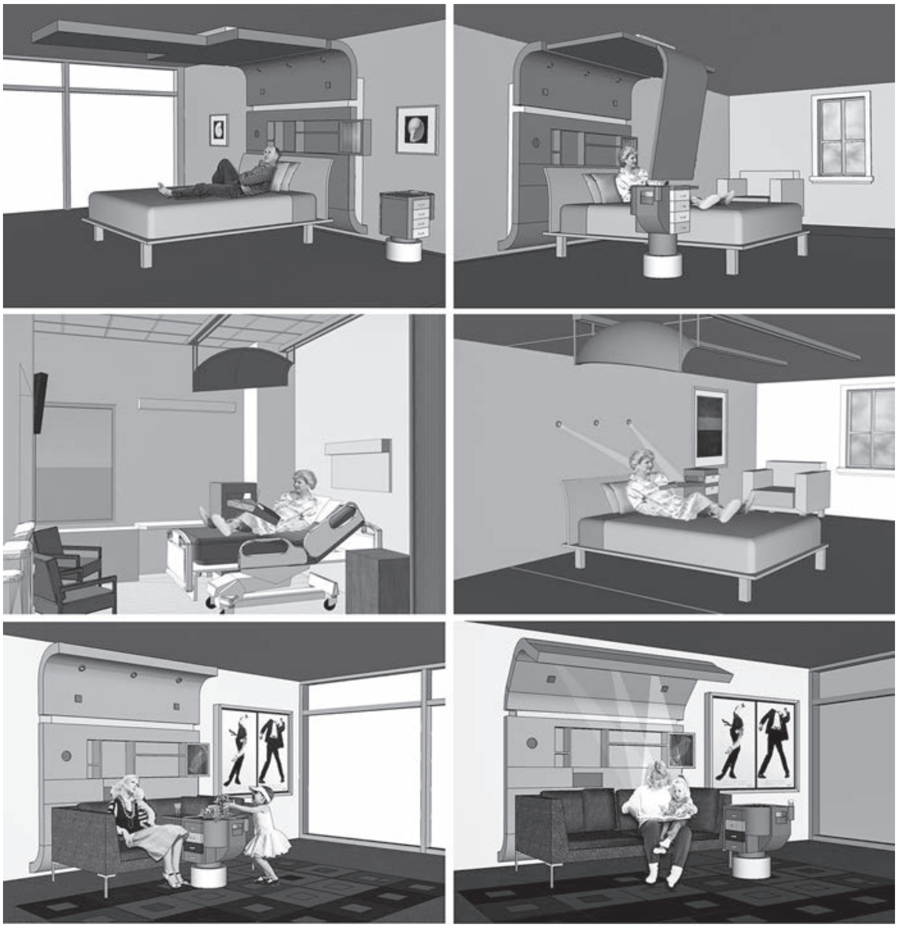

Figure 16 *home+*, in concept, at home and hospital.
Source: author.

Robotics, and Medicine, has to date been manifested as several digital simulations as well as to-scale and full-scale prototypes of the home+ suite of furnishings.[2] In conceptualising *home+* initially, the team quickly prototyped the *home+* concept as an integrated vision, in all its complexity: the design of various furnishings interacting with one another and their users in a specific built environment, a studio apartment that we had designed purposefully for this research. Unlike the typical user engineering approach, we elected to realise this early prototype before we had acquired sufficient data to responsibly guide it (in a measured, industrial design and engineering sense). The virtue of our quick and

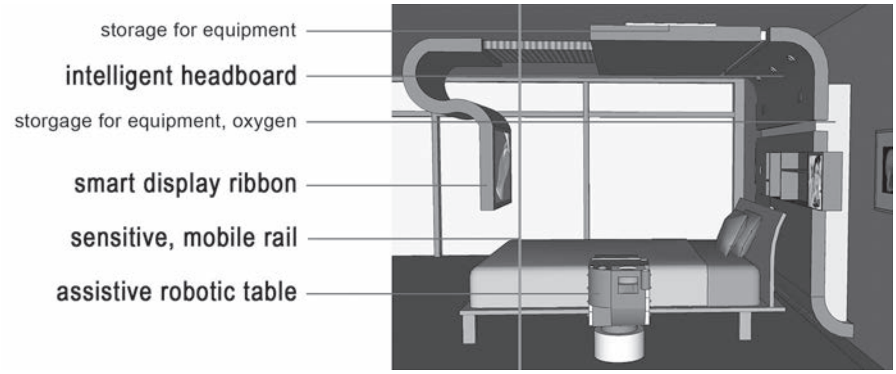

Figure 17 *home*+ components.
Source: author.

early prototyping activity permitted us to get past the inevitable mishaps and unfruitful pathways to a *home*+ design.

1. An *Assistive Robotic Table* gently folds, extends and reconfigures to support therapy, work and leisure activities.
2. An *Intelligent Headboard* adapts to the profile of the patient's back, morphing its supportive surface periodically to alter the patient's position as a vehicle to ensure against bed sores. The *Intelligent Headboard* also offers storage, accommodates an oxygen tank as required and provides intelligent lighting for reading, work activities and ambient illumination.
3. A *Sensitive, Mobile Rail* is not unlike the vertical tubular-metal post found in metro cars – except that this one moves with you, providing more or less assistance, like the arm of a friend, as the user moves between one location within the dwelling to another location, tracing the most common paths travelled in the course of a day. As envisioned, the *Sensitive, Mobile Rail* recognises how much assistance you may need, and 'backs off' from supporting the user when it senses the user is managing fine with less of its help.
4. *Intelligent Storage* manages, stores and delivers personal effects (including medical supplies), and communicates to caretakers when eyeglasses and other belongings are not moved over a period of time.
5. A *Personal Assistant* (not shown in these figures) retrieves objects stored around the room and away from the bed. The robot uses a vision-based recognition system via wireless communication to ensure that the robot retrieves the correct item.

These five components of the *home*+ suite of furnishings recognise and communicate with one another in their interactions with humans and, we envision, with still other *home*+ components. Figures 16 and 17 provide an impression of how the system may look and behave (and not its fixed, pre-determined design). Indeed, towards realising the larger, distributed system of robotic furnishings, the research team persists in continuing iterative design and evaluation of the *home*+ concept, generating alternative, conceptual visualisations of *home*+ and prototyping numerous physical, functioning prototypes of its individual components, identified here and otherwise.

The Assistive, Robotic Table (ART)

As the research team wished to focus its effort not only on the big vision of the *home*+ concept but on a more developed and refined component of it, we dedicated considerable efforts on the *Assistive Robotic Table* (ART), given its relative complexity within *home*+. Our aim was to develop this key component as a fully functional prototype developed with the participation of clinical staff.

ART (Fig. 18) is a hybrid of the typical nightstand found in homes, and the over-the-bed table found in hospital rooms. We envision ART integrated into the domestic routines of its users, even as users transition from home to clinic and, it is hoped, home again. Our research team hypothesises that users employing ART as part of their domestic

Figure 18 The assistive robotic table (ART) – our final, fully functioning prototype.
Source: author.

landscape will live independently, longer. Moreover, we expect ART to free familial caregivers from performing certain arduous tasks for ART's target populations, allowing caregivers to devote more energies to meaningful, human interaction with ART's users. In medical facilities, ART aims to augment the rehabilitation environment by improving patient well-being, rehabilitation and staff productivity (in this vexing moment of limited resources).

Along with the larger *home*+ environment to which it belongs, ART benefits from the convergence of advanced architectural design, computing and robotics largely absent from prior efforts in assistive technologies. In particular, this *enabling technology* is not distributed everywhere in the physical environment but *where it is needed*. It is not intended to be invisible (as per ubiquitous computing) but *visible, attractive and integral* to the home and the patient room *by design* and it is not meant to serve as a means for surveillance but rather as environmental support that recognises and dignifies what people can do for themselves.

These attributes of ART and the larger *home*+ environment are of a kind identified by Donald Norman as 'the next UI breakthrough', defined by 'physicality', and accomplished with 'microprocessors, motors, actuators, and a rich assortment of sensors, transducers, and communication devices'.[3] In broad theoretical terms, Nicholas Negroponte anticipated ART and the larger *home*+ environment in the 1970s in his vision of a 'domestic ecosystem' that regulates aspects of 'environmental comfort and medical care'.[4] More recent inspirations for ART include Malcolm McCullough's plea for 'architecturally situated interactions', which 'permit the elderly to "age in place" in their own homes'.[5]

Physically, ART is a significant development of the over-the-bed table commonplace in hospital patient rooms. What distinguishes ART from the conventional over-the-bed table is its novel integration of physical design and functioning, coupled with an interactive human–object interface (Fig. 19). Integral to ART is a novel, plug-in, *continuum-robotic* therapy surface that helps patients perform upper-extremity therapy exercises of the wrist and hand, with or without the presence of the clinician (refer to Figs 21 and 24). Considered in depth shortly in this chapter, ART's *therapy surface* was recognised as a key requirement of ART, following our early conceptualisation of the larger *home*+ vision, and as a significant outcome of our ethnographic investigations in the clinical setting (or in the 'wild', as human–computer interaction (HCI) defines territories situated outside the lab). These ethnographic investigations suggested the promise of the *therapy surface* for rehabilitating

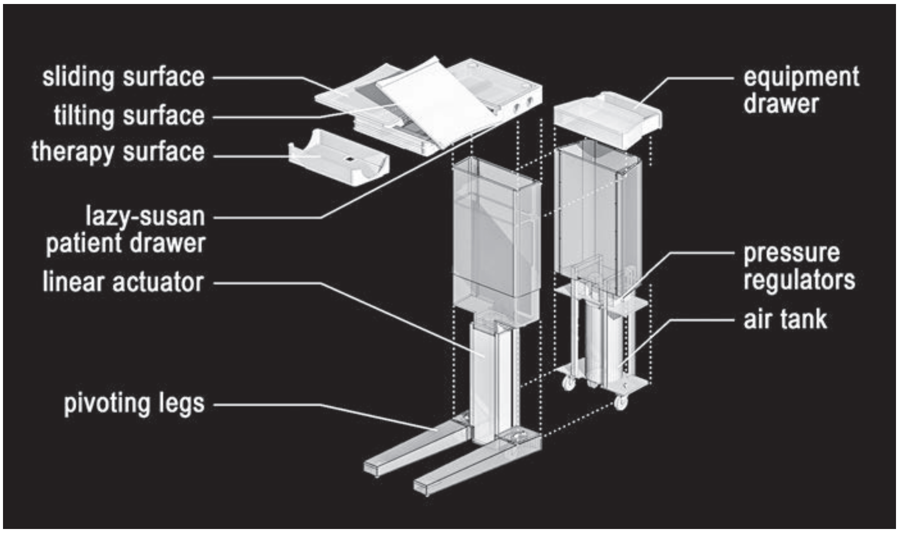

Figure 19 ART's key components.
Source: author.

in particular the upper extremities (upper limbs) of post-stroke patients. Beforehand, it is useful to become acquainted with ART through a scenario, a hypothetical narrative telling the happy story of Amy meeting ART for the first time. Amy had a stroke and has right hemiplegia (paralysis of the right extremities) and aphasia (speech and language problems). After treatment in the hospital, Amy returned home, fitted with *home+*, the same suite of robotic-embedded furnishings that supported her in her patient room. *home+* has uploaded Amy's preferences as acquired from her hospital stay, and modifies these preferences and those of her caregivers over time to best support Amy's recovery. Amy relies on the *Assistive Robotic Table* of *home+* every day (Fig. 20): its *therapy surface* helps Amy rehabilitate her arm; ART tilts and changes height to best accommodate Amy's activities; ART's non-verbal lighting cues remind Amy to take her medications; and ART learns and adapts to the gestures, a form of nonverbal communication that Amy performs with her right arm as she regains more capacity in moving it. ART logs Amy's reading time as a wellness metric, and ART initiates storage of Amy's reading glasses when she has finished reading. These functions and others help Amy improve more quickly. ART's components recognise and partly remember, communicate with, and cooperate with her, her caregivers and the other components of *home+*, empowering Amy to remain in her home for as long as possible, even as her physical capabilities alter over time; and, in more grave circumstances, affording

Figure 20 In the hospital with ART and 'Amy': six instances.
Source: author.

Amy some semblance of feeling 'at home' as she moves to an assisted facility also equipped with *home*+.

While this storytelling acquaints us with ART, we also know from life experience that good stories don't always translate well to the real world. Accordingly, in developing the full-scale, full-functioning ART prototype, my research team needed to subject ART to the clinical environment where healthcare assistance is delivered and received (see Fig. 21). In so doing, we conducted five iterative phases of research.[6] We involved healthcare physicians and occupational, speech and physical therapists. We conducted these research activities within the aforementioned studio apartment of our own design, our purpose-built *home*+ lab at the

Figure 21 ART in the hospital, undergoing evaluation.
Source: author.

Roger C. Peace Rehabilitation Hospital of the Greenville Health System (Greenville, South Carolina, USA). As patient populations of rehabilitation hospitals typically have a high number of post-stroke patients, and as such patients partake in therapies employing over-the-bed tables, the post-stroke population was a particularly apt target for our research on the design of a forward-looking, over-the-bed table.

Convivial or Enslaving

There is no doubt that assistive technologies like ART and the larger *home+* suite of robotic furnishings to which it belongs is urgently needed. The global population continues to age, healthcare costs have been increasing, and there is a smaller segment of society to both care for and pay for the well-being of older and clinical populations. It is estimated that by 2025, in the United States as in many nations around the globe, there will be a shortage of physicians and nurses, and by 2040 there will be more than 79.7 million adults in the United States alone who will be 65 or older – a 92 per cent increase from 2011. *home+*, the response from my research team, strives to reduce the burden on healthcare staff (to deliver their services) and a decreasing tax base (to pay for this service), while meeting patient needs and ensuring the well-being of an increasingly older population.

Given these alarming trends, few would doubt the need for such assistive technology; however, the character of it – its behaviours and appearance – is a topic of continued debate. The lively debate over the character of caring robotics was anticipated in a remarkable book, *Tools for Conviviality* by Ivan Illich, in which the author recognises two trajectories for new technologies: one aiming 'to extend human capability', and the other, used 'to contract, eliminate, or replace human function'.[7] Illich classifies the former as 'convivial tools' that foster 'self-realisation'.[8] Convivial tools, writes Illich, 'enable the layman to shape his immediate environment'.[9] 'Manipulatory tools', instead, reduce 'the range of choice and motivation' for the user, destroying his or her capacity to creatively, 'playfully' engage society.[10] For Illich, the convivial tool is exemplified by the public library, an information machine providing resources openly and freely to the public.

In *Tools for Conviviality*, Illich refers to the historical hypothesis that machines were meant 'to replace slaves'. For the discussion of this chapter, note that the word robot comes from the Czech *robota* meaning 'forced labor'.[11] What both astonishes and distresses Illich is that machines, intended to mostly 'replace slaves', ultimately 'enslave' those they intend to free.[12] Illich locates the blame for this unexpected turn in the designers of such machines; that, too often with machines, it is left to their 'designers to determine the meaning and expectation of others' in human–machine interaction without the participation in the design process of a representative group of likely users.[13] Illich's plea is instead to

> give people tools that guarantee their right to work with high, independent efficiency, thus simultaneously eliminating the need for either slaves or masters and enhancing each person's range of freedom. People need new tools to work with rather than tools that 'work' for them.[14]

Indeed, *Tools for Conviviality* was published in 1973, and perhaps recent history suggests that those who design and build machines strive, as my design research team has, to become more enlightened (more convivial) in their approach to design. Co-design, iterative design, human-centred design and participatory design are common terms employed by a not insignificant part of the academic community and industry entrusted to design today's machines. This more inclusive process of designing the most complex and sensitive of artefacts, caring robots, is fundamentally what this chapter hopes to capture.

Robotics that Give

Clearly, home+ and its key component, ART, represent a breed of robotics quite apart from humanoid robots. Whereas the humanoid robot is meant to resemble us and is (given its appearance) expected to behave like us, home+ is a suite of furnishings distributed through an everyday physical space – robotics made integral with furnishings in familiar domestic rooms that, at least typologically, are familiar to us. As well, many humanoid robots (and most industrial robots) rely on rigid links to move, whereas key parts of ART and home+ depend on softer means to more fluid movements, as afforded technically speaking by pneumatics (compressed air, the pressure of which is digitally regulated) and less frequently tendons (steel cables pulled by digitally controlled motors). ART's *therapy surface*, in particular, requires a delicate but exacting 'touch' to impart confidence to patients and their caregivers that it can assist them.

To meet these demands, rigid-link robotics is not a likely candidate. The shortcomings of rigid-link robotics (commonplace in factories and often used for humanoid robots) are comprised of a series of heavy links, few in number, actuated by electric motors. The movements of rigid-link robots are correspondingly stiff but precise, which contrasts significantly with the less distracting, nuanced, and even graceful movements exhibited by ART's *therapy surface*, actuated by pneumatics. A rigid-link, electro-mechanical system is contrastingly heavy and – worse for unstructured environments – unyielding upon contact with another physical mass. In simplest terms, these rigid-link robots don't 'give' when they collide with people and their physical property.

Consider, then, two of the most unstructured environments inhabited by two of the most vulnerable human populations, both of which define the *home*+ context: dwellings inhabited by older people, and healthcare facilities occupied by patients. In these two demanding contexts, the *home*+ suite of furnishings must not only move in a manner that is safe, comprehensible and pleasing to their users, but also be able to 'give' – to be compliant upon contact with people and physical things. In such an intimate setting as *home*+, robotics will inevitably collide with people and their physical property; consequently, they must be made compliant to avoid costly and potentially grave consequences.

Compliant, fluid, graceful kinematics is characteristic of the robotics classification called *continuum robotics* referenced earlier as exemplified by ART's *therapy surface*. An emerging subfield, *continuum robotics*, describes the kinds of robotics with smooth, compliant backbones that render their movement fluid, natural and more life-like. Overall, the smooth movement and softness of *continuum* robots lend themselves to intimate and elicited interactions with users, while stiff and hard, rigid-linked robots are better suited to the demands for strength, repetition and accuracy of industrial applications. As a flexible, continuous 2-D *programmable surface*, ART's *therapy surface* represents a new class of *continuum robotics* capable of contributing to the formation of physical space within the built environment scale.

Recognise that the therapy surface of ART bends in more than one direction (it morphs across its surface). Consequently, the *therapy surface* can assume a multitude of shapes that aren't stiff like commonplace industrial robots, or limited by bending in section alone. Rather, ART's *therapy surface* smoothly morphs in two dimensions (like the sea). Given its continuous and highly manoeuvrable backbone, a 2D continuum robot like ART's *therapy surface* is classified as *invertebrate*. The control of such a robot – the use of sensors, actuators and algorithms to configure it – is a difficult matter. Unlike the control of rigid-link robots, the control of continuum robots often involves controlling for not only bending but also the extension/contraction of the physical mass, as compared to simply controlling the hinging of an axial joint in the typical rigid-link robot, comprised of a limited number of joints.

Let's consider the bending in two different continuum robots in concept: one of these is *one-dimensional* (1D – it bends in section only), and the other is *two-dimensional* (2D). If you take two short segments of a continuum robot and connect them, head-to-head, you then have a continuum robot in the form of an extended line (much like an elephant's trunk). The bending that occurs within each segment of such a linear robot is defined as *one-dimensional*. (A well-known example of this kind of robotic appendage is the *OctArm* developed by Ian Walker, my close research collaborator.) To make the kinematics of a one-dimensional (trunk-like) continuum robot relatively less cumbersome to define, it *theoretically* reconfigures as the 'essentially invertebrate' snake just described, having a much larger number of smaller links that bend at distinct and well-defined points in such a way that each of its segments bends at constant curvature. If, instead of connecting segments head-to-head, you connected them in such a way that they form a surface (for example, three segments to make a triangular surface, four segments to make a quadrilateral surface), and then co-join several such surfaces, you have the continuum robotic surface exemplified by the compliant *therapy surface* of ART. The bending that occurs within each surface of this continuum robotic surface is defined as *two-dimensional*. As such, the kinematics for such a continuum robotic surface is highly complex, as a continuum robot has, theoretically, an infinite number of joints across a surface, rather than along a line (as in *OctArm*) and, consequently, an infinite number of ways in two dimensions to assume its goal configuration. To make the kinematics of a two-dimensional continuum robot surface (like ART's) relatively less cumbersome to define, it *theoretically* reconfigures as a surface of many snakes joined to one another, at their sides, so that stretches of this surface has constant curvature. Consequently, the problem of determining the shape of this robotic surface, its kinematics, is simplified compared to a determination made on the basis of the curvatures of a considerable number of very short segments of the surface. But even when characterising the ART surface (and continuum robotics generally) as *essentially invertebrate* robots exhibiting constant curvature, the number and complexity of terms involved in their kinematics can be formidable. (The kinematics for such a surface is reported in a technical paper authored by our research team.)[15]

A more tangible way of understanding continuum robotic surfaces, and so, ART's *therapy surface*, is through the qualitative study of functional, physical prototypes. To realise ART's *therapy surface,* my research team built a working prototype from a square surface of conventional foam (36 cm on a side), two McKibben actuators, some zip ties to fasten the actuators to the foam surfaces and a Kinect from Microsoft's computer gaming system. McKibben actuators are artificial muscles (that is, bladders) that expand and contract as they are filled or depleted of compressed air. According to the recipe advanced jointly by my lab and by the co-joined lab of my close collaborator, Ian Walker, we built our own McKibben actuators using high-temperature, silicone rubber tubing, expandable mesh sleeves, nylon reducing couplings and nylon, single-barbed, tube-fitting plugs (refer to Fig. 23). Digital pressure-regulators control the precise pressure of air delivered to the actuators. Flexible tubing connects the system of actuators, regulators, the air compressor (a common air tank will do) and the control computer (a common laptop will do). We attached two actuators to the square surface of sheet foam in four different orientations: running the actuators in parallel, forming a perpendicular ('Swiss') cross with them and making 45 and 90 degree angles of them. We marked twenty-five points on the square surface that we tracked with the Kinect sensor, each point being either 8 cm or 10 cm from the previous point. For each muscle arrangement, two sets of data were collected. The first set of data measured the depth (the distance of the point on the surface from the sensor) of the *un-actuated surface*. The second set measured the depth of the points on the *actuated* surface by using a computer programme that allowed the user to select feature points in two different image frames. The selected points in the first image frame captured the depth for the *un-actuated* surface at each point, and the selected points in the second image frame captured the depth for the *actuated* surface at each point. With respect to the surface, the Kinect sensor was positioned directly in front of it, at the same height of it and parallel to its surface. To calculate the distance that each point on the surface moved in the x-direction (that is, the height that the surface moved), the actuated data was subtracted from the un-actuated data. Once the x-distance data had been calculated for each point, the x-distances for the same points were calculated using the appropriate (that is, muscle-arrangement dependent) kinematic model; then, the mean square error (MSE) between the two distances was calculated. Additionally, the MSE between the same kinematic data and the physical data for an un-actuated surface, which would have x-distances of zero, was calculated for comparison. This MSE would represent the worst-case scenario and should, therefore, be larger than the MSE for the actuated surface. If all this is a bit difficult to follow, Figure 22 conveniently visualises the outcome that the theoretical kinematics for the different muscle arrangements reasonably approximated the data we collected from testing the physical surface.

The analytic exploration just described guided the more complex design of ART's *therapy surface*. Rather than two actuators bending a square sheet of foam, the *therapy surface* (Fig. 23) was actuated by multiple actuators and required exacting behaviours that match five therapeutic exercises for the upper limbs performed by post-stroke patients, and guided by physical therapists working without any medical devices during physical therapy sessions.

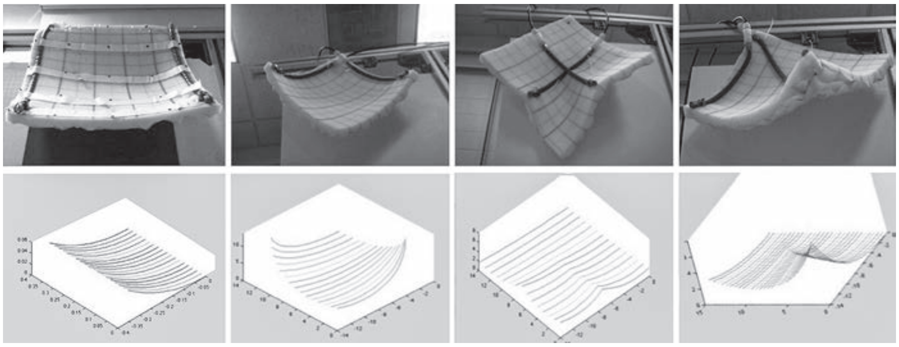

Figure 22 Evaluating the therapy surface's kinematic models: qualitative versus simulated results.

Source: author.

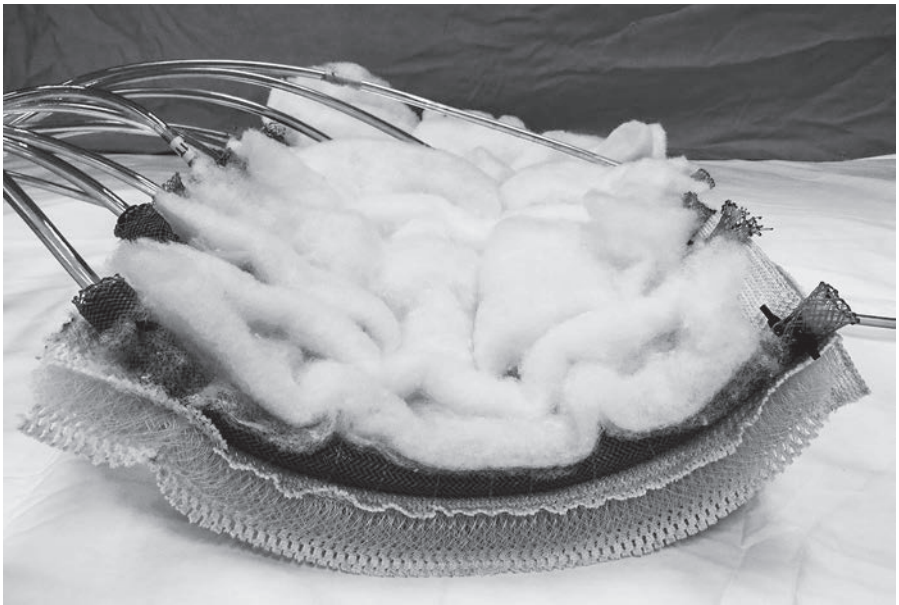

Figure 23 ART's therapy surface – working prototype.
Source: author.

With these starting points in mind, the research team iteratively designed and evaluated the therapy surface in tandem with the larger five-phase ART investigation (referenced earlier), translating the early studies (with the foam square and two actuators) into a rehabilitative robotic surface. Notably, in phase one, specifically through observations of therapy sessions, the research team drew three inferences that would significantly impact the therapy surface's design requirements. First, we inferred that our continuum surface could perform many therapeutic exercises, including wrist flexion and extension, forearm pronation and supination, flexor synergy, shoulder flexion, shoulder rotation and cross-body movements as well as arm cupping for support. Second, we inferred that these same exercises were sufficiently commonplace in therapy sessions so that our therapy surface would prove useful. Third, we inferred that our surface could provide enough variability in the movements of these exercises to accommodate various injury levels and types.

In our design development, we ultimately divided the therapy movements into those that can be achieved by our continuum robotic surface (wrist extension and flexion, forearm cupping, forearm *pronation* and

Figure 24 ART's therapy surface performing a therapy.
Source: author.

supination) and those that can be achieved simply by the movement of ART on which the continuum surface was mounted: flexor synergy, shoulder flexion, shoulder rotation and cross-body movements. To assess how well the various behaviours of the robots matched the expectations of the therapists for each of these exercises, we prepared and presented a video of the various therapy movements performed by the prototyped surface to a group of therapists, and asked them the following:

Is this how you would perform wrist flexion?
Is this how you would perform wrist extension?
Does this device offer enough variability for various patient types?
Would you use this device?
Do you think a patient would use this device?
Do you think this device is safe?
How does this device improve therapy sessions?
What information would you want this device to gather?
What other therapy movements do you think the device can perform?

The five iterative phases of design research resulted in a comprehensive prototype of a continuum robotic surface for stroke rehabilitation therapy that garnered positive and promising responses from the clinicians.

The *Vortical*: Thinking about Architecture and Engineering Differently

ART's *therapy surface*, characterised as smooth, continuous, flowing and dynamic, suggests a very different way of thinking about surfaces in architecture like walls, floors and ceilings. As already considered for ART's *therapy surface*, soft, smooth, fluid reconfigurations are essential to its success as it supports and enhances everyday human activities in, very often, intimate confines. Figure 25 provides a summary of four 'soft robotic' efforts, conceived by me and my close collaborator, Ian Walker, which are counter to a rigid-link, robotics approach. Similarly, Figure 26 captures in graphic, even macabre terms our concept of *home+*, where we imagine a humanoid robot being dismembered as limbs, head and

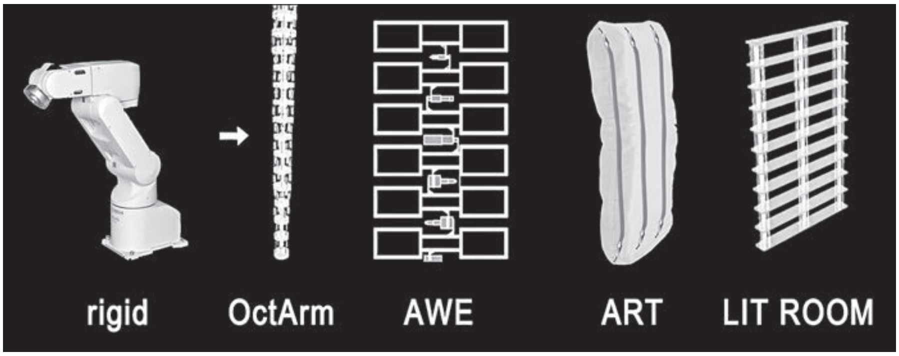

Figure 25 A summary of four 'soft robotic' efforts from the research labs of the author and I. Walker, which are counter to a rigid-link robotics approach (far left) (diagram by the author).
Source: author.

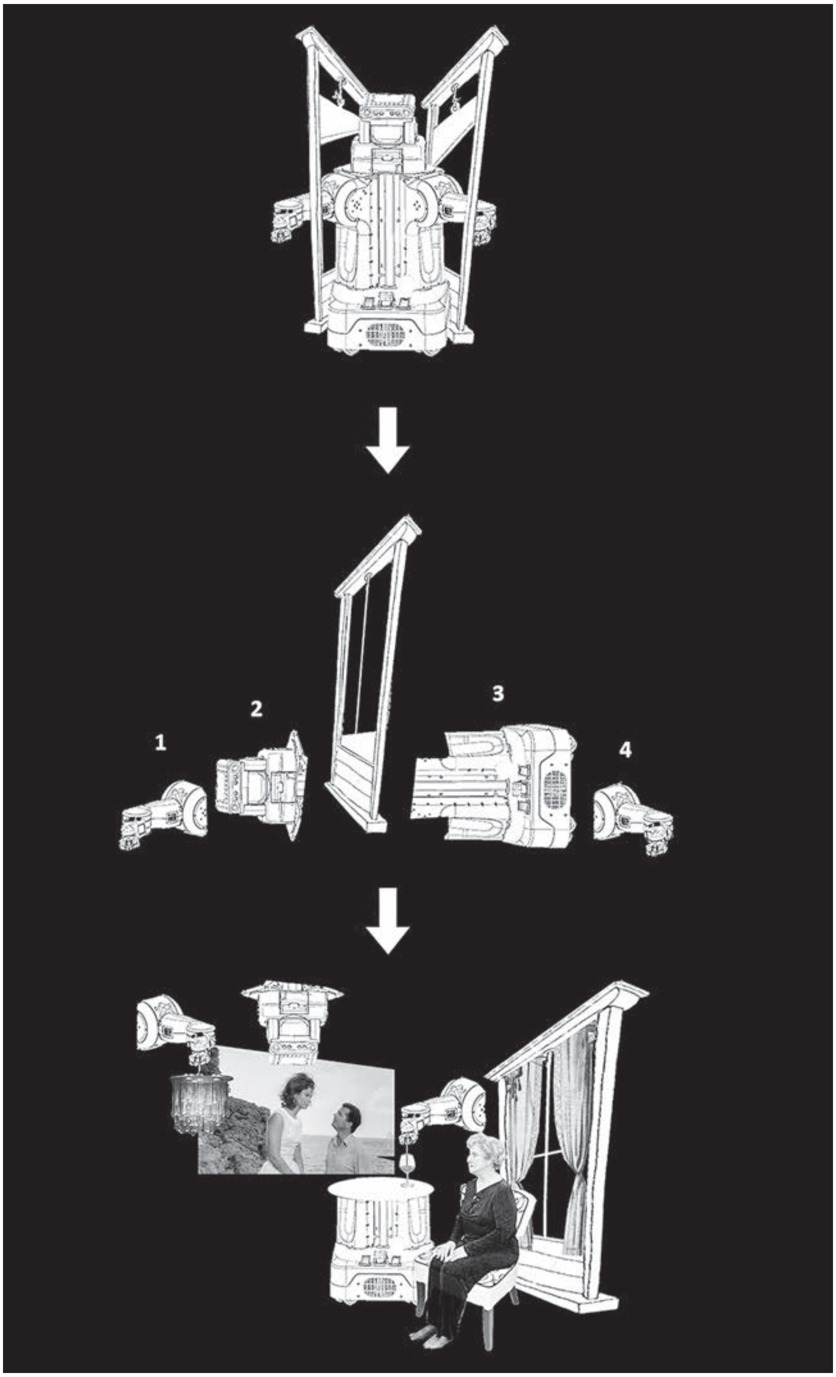

Figure 26 From a humanoid robot to a *living room* (diagram by the author).
Source: author.

torso that we re-package and fine-tune as a *living room* full of lively, distributed furnishings, each one tuned to specific tasks and playing its part, each one knowing something about the others and something about you.

By now it should be evident that robotics embedded in (that is, integral with) the built environment (from the scale of furniture to that of the metropolis) opens up a very different way of conceptualising architecture. The notion that the physical mass of an architectural work is set in motion by robotics, reconfiguring its spatial quality, disrupts our fundamental understanding of Architecture as *firmitas*, in its being firm, constant, solid, static and stable. When robotics is integral with the physical fabric of architecture (at wide-ranging scales) is classified as continuum rather than rigid link, its *firmitas* (that is, firmness, stasis, constancy) is arguably more upended, as the architectural work is not only moving but, in a way, quivering as if it were alive, and shape-shifting into something that seems foreign to what it was at an earlier point in time.

Before ending this consideration of ART's *therapy surface*, it is therefore useful to ponder the questions suggested by it, and the larger ART artefact, and our vision of the *home+* to which they belong, and finally to the World Wide Web and the Internet of Things as speculated in the concluding remarks of this chapter: *What kind of place is this?* and *How does it reflect our current state* (or, you may say, *disposition*)*?* In a curious way, French philosopher Gilles Deleuze and psychoanalyst Félix Guattari together ponder the second question literally and abstractly, in *A Thousand Plateaus*. In the twelfth 'plateau', exploring the relationship between the State and its military, Deleuze and Guattari posit two models of thinking and acting that, strangely, provide a compelling perception that applies well to ART and *home+* – the kinds of places they make, and how they reflect, interact with, and somewhat become us.[16] These two models are the *authoritative model* exemplified by the State, and the *vortical model* exemplified by the military. Architectural Robotics, as offered here, is very much the latter, and Architecture and Engineering, very much the former.

The *authoritative model* is characterised by: the straight line, the parallel (laminar) flow, solid things and a spatial environment that is closed, striated and sedentary. In its propensity to edify and monumentalise, Architecture and Engineering, argue Deleuze and Guattari, have 'an apparent affinity for the State' and its authoritative model. The *authoritative model* is manifested in the built environment as 'walls, enclosures and roads between enclosures', 'bridges', 'monuments' and, generally, a 'metric plane' that is '*lineal, territorial, and numerical*'.[17]

In contrast, the *vortical model* is characterised by: the curvilinear line, the spiral (vortical) flow, the flow of matter and a spatial environment characterised as open, smooth, flowing and fluid.[18] Free flowing and measureless, the *vortical model* is manifested in the natural environment in the desert and the sea.[19] Outside of its manifestations in nature, the *vortical model* is exemplified by the intermezzo of music, the space of Zen, and in the built environment (in a rare exception) as the impossibly slender, sky-reaching Gothic cathedral.[20]

More generally, Deleuze and Guattari characterise the vortical space as 'vectors of deterritorialisation in perpetual motion'.[21] Additionally, Deleuze and Guattari, referencing phenomenologist Edmund Husserl, describe the vortical space as a 'fuzzy aggregate', 'a kind of intermediary', 'vague' and 'yet rigorous'.[22] Something of the same is central to the thinking of Manuel Castells in his concept of the 'space of flows'.[23] For Castells, as for Deleuze and Guattari, the fluid, vortical 'space' is a way of thinking and making that finds validation in our propensity for 'neurological play', in the lure of controlled 'ambiguity' that 'engages and challenges the brain to allow multiple meanings'.[24]

If this philosophical equation between form and thinking seems itself vague and ambiguous, we need only walk the linear boulevards that cut through Paris, Rome and Washington, D.C. to connect urban form to figureheads (Napoleon III, Mussolini, George Washington). Today, we have not the grand boulevard but rather the kingly quarters of the private domain, exemplified by Apple's new Cupertino headquarters. Accommodating some 12,000 Apple employees, this five-billion-dollar building designed by Foster + Partners (with Arup as engineers) takes the form of a perfect glass circle defining a perfectly circular courtyard. No matter how elegant its glass skin, this closed, *authoritative* form – an apple without the bite – chillingly evokes Dave Eggers' aptly titled *The Circle* that chronicles a tech employee caught in the web of a colossal, oligarchical Information Technology (IT) company.

The other side of this equation, *the vortical*, surfaces in the architectural writings and works of Robert Venturi (often times, in collaboration with his wife, Denise Scott Brown) in his theory of a '*both-and*' architecture, rather than an '*either-or*' architecture: an architectural work characterised as *both* complex *and* contradictory, *both* high-culture *and* low-culture, *both* contemporary *and* drawn from history.[25] Much like Venturi but from the perspective of robotics and not architecture, Rodney Brooks envisions a future in the *both-and* – both organic and mechanical.[26] Suggesting that the convergence of human intelligence and machine intelligence will come only by way of a new conceptual framework, outside that of digital computing, Brooks calls for a bio-technical body, and sees its emergence in our becoming increasingly more robotic (by way of, for instance, advanced prostheses) while robots are becoming more biological (in their capacity to sense, adapt, learn, move and otherwise actuate).[27] Presumably for Brooks, we will meet one day in the middle: human-machine, machine-human.

But unlike Venturi's dialectical, physically static, and aestheticised *both-and* architecture, and taking a more tempered view of Brooks' prophetic, bio-technical body, *home*+ and its ART suggests a very different way of thinking about architecture and robotics today, whereby architecture is more than an aesthetic search or a stylistic path, and robotics, more than a technological quest. Something at the threshold between architecture and robotics and their long-standing concerns is captured in Deleuze and Guattari's 'Concrete Rules and Abstract Machines', in which they define a novel 'technological plane', as

> not simply made of formed substances, aluminum, plastic, electric wire, etc., nor of organising forms, program, prototypes, etc., but of a totality (ensemble) of unformed matters which present no more than degrees of intensity . . . and diagrammatic functions which only present differential equations.[28]

With ART as its key component, *home*+ represents a start to realising the dream of a *living room*, a distributed suite of robotic furnishing that 'come to life' in the ways De Chirico dreamt – furnishing that know about us, and know about one another. Furnished with this information about itself and its surroundings, the *home*+ *living room* reconfigures, smoothly and softly, to support us in our everyday lives. But more than this, the convergence of architecture and robotics, as manifested as *home*+, promises new vocabularies of design, and new, complex realms of understanding ourselves in this dynamic, expanding ecosystem of physical bits, digital bytes and biology.

Speculations on Scaling Up

Had Ivan Illich written *Tools for Conviviality* today, he would surely have recognised today's *starchitecture* shaped by a short list of globe-trotting architect-stars as epitomising his classification of the manipulatory tool, an architecture designed by individual geniuses with little or no participation by its likely inhabitants, funded by the wealthiest, mostly private patrons, and servings as iconic status symbols – works of art of the largest physical scale that anchor a portfolio beheld by those who can pay for it. Likewise, Illich today would surely have recognised the computing *apps* and operating systems shaped by Apple, Microsoft, Facebook, and other oligarchical IT entities as epitomising the manipulatory tool: tracking what we do, whom we know and what we prefer – a control system ripe for abuse. Can we envision another future where architecture and computing converge, a more convivial and caring future outside starchitecture and these operating systems and applications, outside the World Wide Web, outside the Smart City or *e-topia*? May we say – instead, in a bit of a silly way – that the future where architecture and computing converge resides on *cyberPLAYce*, at once local and global, physical and digital?

While it may not be possible to disconnect from the Internet for long, and arguably it may not be desirable to do so, imagine a future that relies less on the *net* and more on a cyber-physical *mesh network*: a digital-physical communications network far looser than the Internet and its associated apps and operating systems – less formalised, less oligarchical, more decentralised, more community-responsive, more ad hoc, more localised and more fine-tuned to individual needs and opportunities. Like a wireless mesh network, this more expansive, playful plan for the convergence of architecture and computing, *cyberPLAYce*, is populated by cyber-physical nodes of activity that may or may not form a vague connectivity with one another.

What does cyberPLAYce look like? How does it behave? How do we design it? Indeed for any relevant designer of architecture, computing systems and their hybrids working today, 'the primary design question is how to architect a complex system to be extendable to multiple arbitrary scales in time and space'.[29] On cyberPLAYce, the design response may look and behave something like this: distributed cyber-physical nodes decoupling from and re-engaging the Internet to relative degrees, as determined by local situations defined partly by human–machine interaction and partly by individual and community control. How such nodes receive, transmit and interpret signals from one another is defined as 'interoperability on a systematic level'.[30] Such interoperability across cyberPLAYce has the potential to provide more apt, more assistive, more augmenting computing resources to individuals and their local communities. What the oligarchical entities receive in return for relinquishing a bit of pervasive control to these more localised mesh networks is focused, localised tutoring of their Artificial Intelligence (AI) platforms, as well as the knowledge required to deliver more focused content to individual cyber-physical 'neighbourhoods'.

To make CyberPLAYce more tangible, let's refer to a modest interactive and adaptive built environment just underway in my research lab that would especially benefit from such a network. LIBRARY-CUBED is a physically reconfigurable, technology-rich library unit, ten foot on a side, that can be installed in branch libraries or other public buildings in underserved communities. Accordingly, a single LIBRARY-CUBED, a single 'architectural robotic' node, can exhibit a variety of connectivity conditions: it may function off-line; or it may join the Internet for increments of time or continuously; or it may form a mesh network, for increments of time or continuously, with other LIBRARY-CUBEDs or, maybe, LIBRARY-CUBEDS and some services at the library, staffed by librarians; or it may form a mesh network (as above), which in turn connects to other mesh networks for increments of time or continuously. In this computing-future, the information transmitted across individual nodes doesn't flow evenly throughout the mesh network, but 'hops about' to neighbouring nodes as affinities arise from interactions between itself, people and the things around and inside it: that amalgamation of physical bits, digital bytes and biology, at a given instant. As well, recognise that while such an underserved community may never see the likes of a library designed by a *starchitect*, it may nevertheless have 'high-design' delivered to it in the form of this compact, architectural-robotic 'package'. Such a package, installed in an existing civic building in underserved neighbourhoods, is capable of reconfiguring in ways that offer many of the architectural experiences that may fill the much larger volume of the main library, designed by the starchitect, found in the wealthiest cities. This cyber-physical system is of a kind that can create a small home – *your home, your neighbourhood* – for architecture and computing resources.

While the overwhelming tendency in architecture and computing is to globalise*, cyberPLAYce has the potential to domesticate*. On a typical day on cyberPLAYce, cyber-physical artefacts of all scales and capabilities collectively create a commodious, convivial home for you, situating your meaning within a broader networked world that yet provides you some locus of control. This future where architecture and computing converges, promises a robust, dynamic, strategically decentralised, ecological, bottom-up platform for the cooperative interaction across computing, the built environment and people. This would be Illich's convivial society, 'designed', in his words, 'to allow all its members the most autonomous action be means of tools least controlled by others'.[31]

Notes

1. Nocks, *The Robot*.
2. This aspect of the research is elaborated in Threatt et al., 'Vision of the Patient Room'.
3. Norman, 'Next UI Breakthrough'.
4. Negroponte, *Soft Architecture Machines,* pp. 127–8.
5. McCullough, *Digital Ground*, p. xx.
6. These five phases of research are further elaborated in Threatt et al., 'Assistive Robotic Table'.
7. Illich, *Tools for Conviviality*, xii.
8. Ibid. p. 24.
9. Ibid. p. 34.
10. Ibid. p. 29.
11. The term 'robot' was coined in K. Čapek's 1920 play, *R. U. R.* ('Rossum's Universal Robots').
12. Illich, *Tools for Conviviality*, p. 10.
13. Ibid. p. 21.
14. Ibid. p. 11.
15. Merino et al., 'Forward Kinematic Model'. In this section, I'm also indebted to Jessica Merino for her MS thesis work in our lab. Merrino, *Continuum Robotic Surface*.
16. Deleuze and Guattari, *Nomadology*. (*Nomadology* is the English translation of a chapter from *A Thousand Plateaus: Capitalism and Schizophrenia.*)
17. Ibid. pp. 88, 51, 22, 45, 30 and 63 (the last, with italics by Deleuze and Guattari).
18. Ibid. p. 18.
19. Ibid. p. 48.
20. Ibid. pp. 50, 45, 22.
21. Ibid. p. 62.
22. Ibid. p. 96.
23. Castells introduced the concept of 'space of flows' in his *The Informational City*. With respect to the consideration of this book, see also Castells, *Rise of the Network Society.*
24. Mallgrave, *Architect's Brain*, p. 149.
25. Elaborating this theory is a canonic book for the discipline of architecture, Venturi, *Complexity and Contradiction in Architecture*. Ignasi de Solá-Morales and his concept of a 'Weak Architecture' is arguably a better reflection of vortical thinking than Venturi's dialectical both/and (see Solá-Morales, 'Weak Architecture').
26. Brooks, 'I, Rodney Brooks, Am a Robot', p. 73. In this instance again, there is a marvelous analogue in architectural thinking found in Rykwert, 'Organic and Mechanical'. Here Joseph Rykwert traces the co-mingling of the terms 'organic' and 'mechanical' in architectural thought, beginning

with Vitruvius's treatise (where 'the Latin oganicus did not mean anything very different from machinicus'), to Gottfried Semper, Owen Jones and John Ruskin (all of whom cultivated 'ideas about a new way of imitating nature, or relating the organism to the built form') (pp. 13 and 17). In the conclusion of his paper, Rykwert laments that while architects have long been preoccupied with nature as inspiration for decoration and form, there is not yet a 'theory of architecture based on a direct appeal to . . . the nature that biology and chemistry study' (p. 18). Perhaps some aspects of this chapter represent small steps in the direction that Rykwert had anticipated.

27. Brooks, 'I, Rodney Brooks, Am a Robot', pp. 73–4.
28. Deleuze and Guattari, 'Concrete Rules and Abstract Machines'.
29. Horváth, 'What the Design Theory of Social-Cyber-Physical Systems Must Describe, Explain and Predict?', p. 116.
30. Kominars, 'Interoperability Case Study'.
31. Illich, *Tools for Conviviality*, p. 20.

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