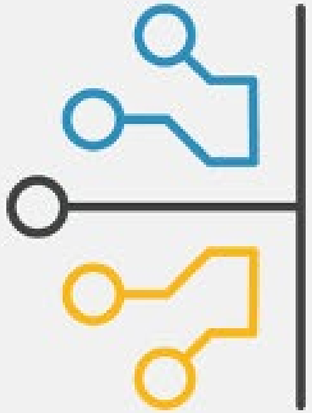
Welcome to



EMERGING TECHNOLOGIES CONFERENCE

at Advanced Textiles EXPO®

Textile Macroelectronics

Architecting Sensate and Computational Fabrics Across Scales

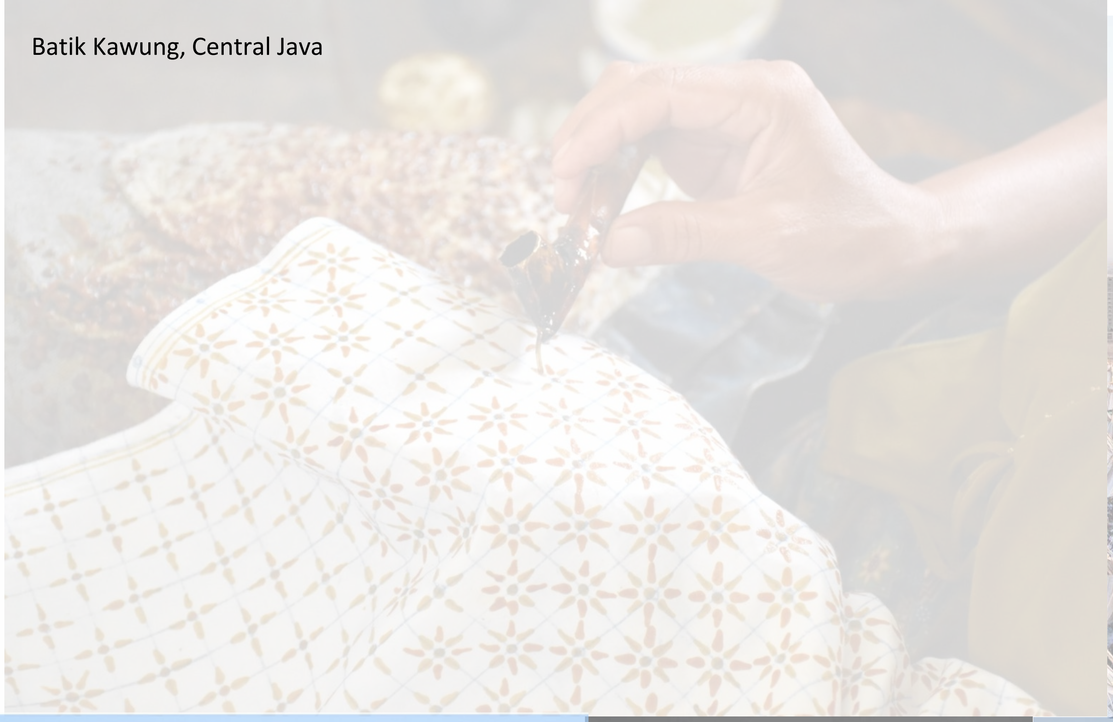
Irmandy Wicaksono (*irmandy@mit.edu*)

Research Affiliate, Responsive Environments, MIT Media Lab

Massachusetts Institute of Technology

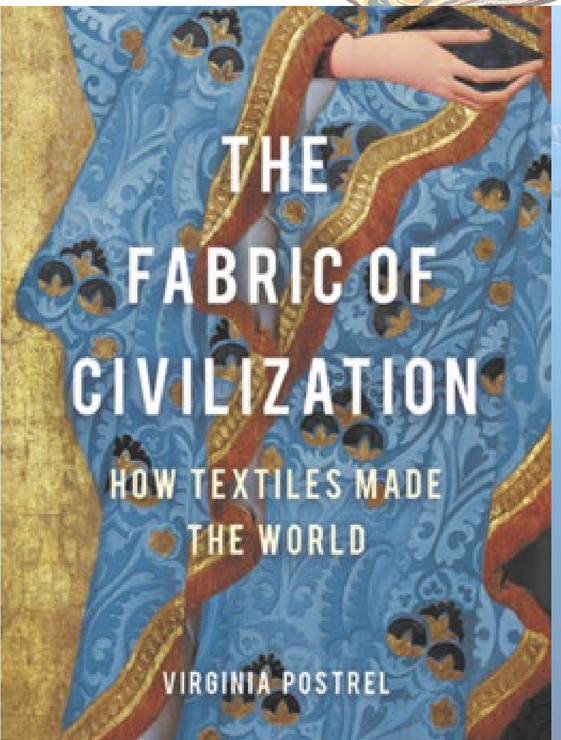
Introduction

Faig Ahmed’s Yahya al-Shirvani al Bakuvi, Melting Carpet



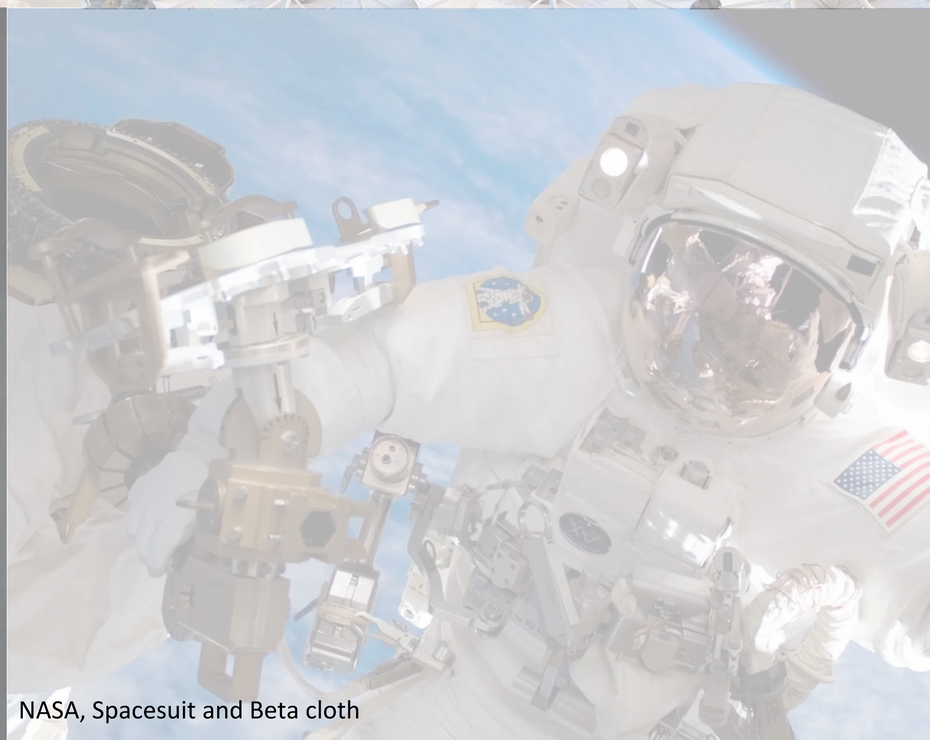
Batik Kawung, Central Java

SEFAR PTFE Fabric, Medina



Surrounded Island, Christo and Jeane-Claude

Flying Saucer, Issey Miyake



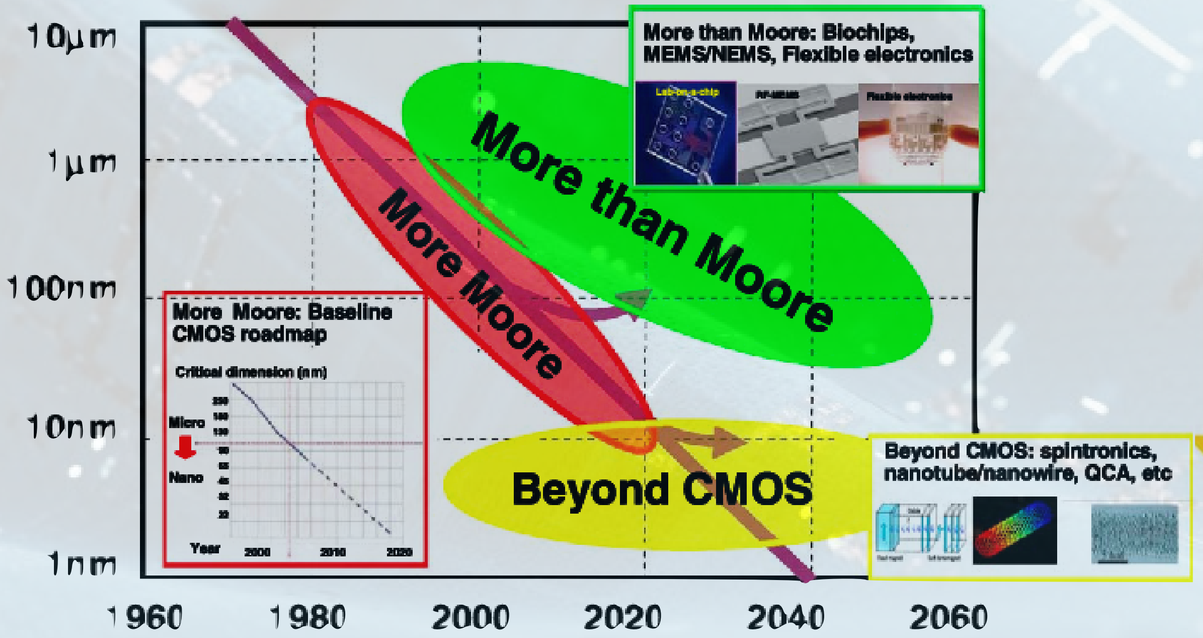
NASA, Spacesuit and Beta cloth

Paula Zuccotti
Everything We Touch (2015)

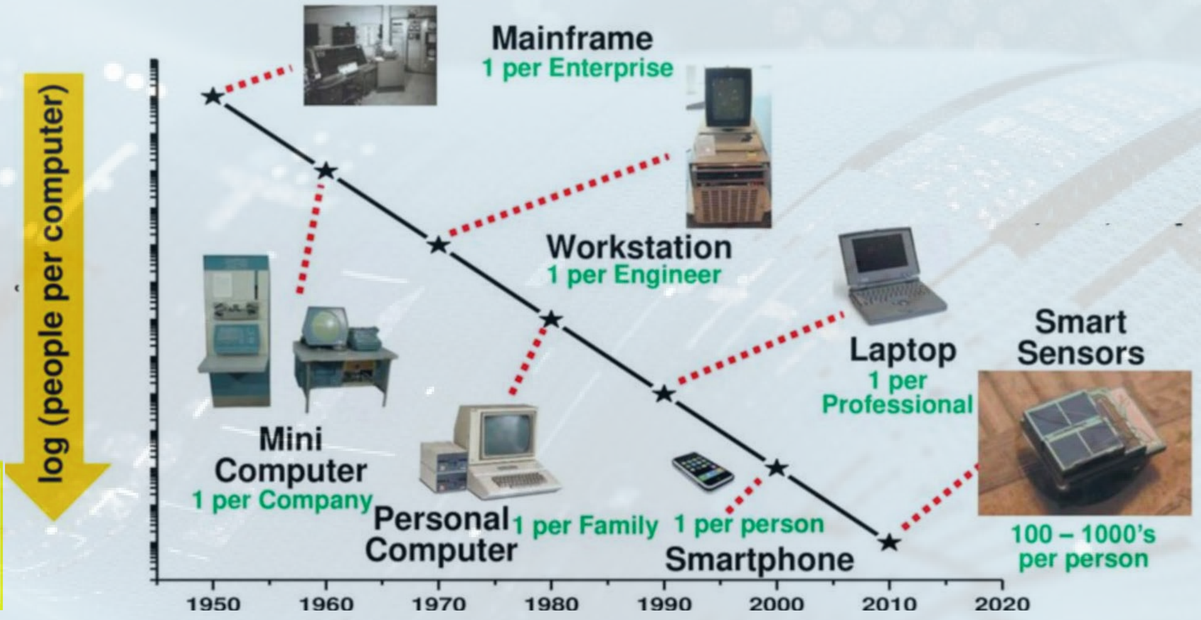
The Computer for the 21st Century (1991)

”The most profound technologies are those that disappear. They weave themselves into the *fabric of everyday life* until they are indistinguishable from it”. *Mark Weiser*

Moore’s and Bell’s Law:
A Ubiquitous Computing Era



Roy et al., IEEE Design and Test (2013)



Gordon Bell, CACM (2008)

Reuss , Hopper, and Parl, MRS Bulletin (2006)

www.mrs.org/bulletin

Macroelectronics

Robert H. Reuss, Darrel G. Hopper, and
Jae-Geun Park, Guest Editors

Abstract

As revolutionary as microelectronics has been as a technology, there are functions that it does not address. Microelectronics focuses on ever-smaller integrated circuits (ICs) in ever-fewer square millimeters of space to increase clock speeds and decrease the power required for computer processing functions. However, applications requiring control, communications, computing, and sensing over a large area are difficult or cost-prohibitive to achieve because of the material incompatibilities of traditional ICs with structures, materials, and manufacturing technology. Macroelectronics addresses these applications with the aim of providing active control circuitry *in situ* over areas of many square meters for displays, solar panels, x-ray imagers, surface measurements, structural shape control, vehicle health monitoring, and other large-system applications. The materials challenges of macroelectronics integrated circuits (MEICs) reviewed in this issue include lightweight flexible substrates, thin-film transistors (TFTs) with IC or near-IC performance, modeling, and manufacturing technology. Compatible component materials, flexible substrates, processing conditions, host system composition, and functionality provide grand challenges that are just beginning to be addressed by researchers.

Keywords: *electronic material, lithography, sensor.*

Electronic devices have become increasingly pervasive over the last 50 years. Advances have been driven primarily by microelectronics, based on the well-known Moore's law that describes the increasing complexity (and therefore performance) as feature size decreases over time. While there are many issues to be addressed, as described by ITRS roadmap,[1] the mainstream microelectronics industry continues to provide ever-increasing performance and functionality. However, other forms of electronics have also become important, as they address problems that conventional microelectronics cannot. The most significant of these is the display industry, which now rivals the integrated-circuit (IC) industry in terms of revenue. The technical drivers for these two major industries are essentially opposite. While the IC industry strives to make the smallest possible devices in the smallest possible area, the display industry is interested in large devices over the largest possible area. This drive to distribute the devices over large areas can be considered "macroelectronics," because neither the active devices nor the area they cover needs to be "micro" in scale.

Commercially viable macroelectronics began in 1988 with thin-film-transistor–based liquid-crystal displays (TFT-LCDs). Direct-view active-matrix liquid-crystal displays (AMLCDs) based on inorganic TFTs on glass substrates represent the first commercial success of macroelectronics. Sales of AMLCDs have superseded the cathode-ray tube in both revenue (2002) and units (2004) to become the dominant display technology on the planet.[2] Examples include the demonstration by Samsung in 2005 of an 82-in.-diagonal screen with six million TFTs controlling the brightness of each of two million color pixels (see Figure 1); a 100-in. AMLCD, announced by LG.Philips LCD Co. in January 2006; and an IBM monitor product introduced in 2002 with a 22.2-in.-diagonal screen, 27 million TFTs controlling 9.1 million (3840 × 2400) color pixels, and a TFT vertical/horizontal pitch of 124.5/41.5 μm. These TFT pitches are about a thousand times larger than those found in ICs. This difference in transistor density may be used as one way to distinguish macroelectronics ICs (MEICs) from classical metal oxide semiconductor field-effect transistor ICs.

Beyond the dominant AMLCD technology, several niche display technologies also use TFT backplanes to drive pixels over large areas and thus are considered examples of macroelectronics. Examples include displays based on organic light-emitting devices, electroluminescent electrophoretic ink, and field-emission mechanisms. Other large-area display technologies are not macroelectronics, as they do not have MEICs built into them. Examples include inorganic light-emitting diodes (LEDs), vacuum cathode-ray tubes (CRTs), and most plasma technologies. The LEDs now popular for jumbo-size outdoor displays in stadiums, billboards, and building facades are not macroelectronics, because they are driven externally by personal computers, not internally by TFT MEICs. The CRT vacuum technologies are driven by analog electronics (e-guns and deflection coils) and are not even digital, let alone macroelectronic. Drive voltages and power are also a distinguishing factor: TFT technologies typically operate at 3–5 V, drawing 1–10 W, compared with 1–20 keV and 1–10 kW, variously, for plasma, CRT, and LED displays. The pixel size in LEDs and plasma are also issues: millions of LEDs are separately packaged and hand-mounted with 10-mm pitch in arrays meant for viewing at hundreds of feet.

Some potential future application areas for macroelectronics are illustrated in Figure 2. These areas include displays (top left and top right), sensors (top right and bottom right), energy harvesting (top right and bottom left), electronics embedded into gear (radios, range finders, computers) and clothing (bottom left), and structural health monitoring of vehicles or humans (bottom right). Structural health monitoring involves a range of sensors, processors, and transmitters built with flexible MEICs within vehicle composite materials to actively sense and report faults, or mounted on/in human biomaterials (skin/tissues) to continuously sense and transmit physiological and cognitive status. The weight and materials integration issues with ICs make these applications impossible or unlikely with a purely microelectronics approach and thus require macroelectronics.

The biggest challenge for macroelectronics technology is to enable applications beyond displays that involve large areas and volumes that cannot be cost-effectively achieved through traditional packaged-chip fabrication followed by pick-and-place assembly and that nonetheless require sophisticated, high-performance circuits. The large scale of macrosystems gives rise to the requirement for properties heretofore not associated with IC applications, such as thinness, ductility, and elasticity of electronic components, even during operation. Depending on specific applications, some design rules for traditional ICs must be maintained (e.g., length of transistor channels) and others relaxed (e.g., area of circuit layout).

As revolutionary as microelectronics and functional devices have been a focus in the last decade, there are challenges that it does not address to incorporate them into our everyday products.

"Applications requiring control, communications, computing, and sensing over a large area are difficult or cost prohibitive to achieve because of the material incompatibilities of traditional ICs with structures, materials, and manufacturing technology."

Reuss , Hopper, and Parl, MRS Bulletin (2006)

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Wicaksono , Cherston, and Paradiso, IEEE PvC (2021)

THEME ARTICLE: COMPUTATIONAL MATERIALS

Electronic Textile *Gaia:* Ubiquitous Computational Substrates Across Geometric Scales

Irmandy Wicaksono, Juliana Cherston, and Joseph A. Paradiso, *MIT Media Lab, Massachusetts Institute of Technology, Cambridge, MA, 02139-4307, USA*

From in-body implantables to geotextiles and large-area spacecraft blankets, electronic fabric is now poised to operate across geometric scales that span many orders of magnitude, and thus across operational contexts with divergent material resiliency requirements, reaching far beyond the wearable device regime that is typically considered. This article reviews the key technical trends and lingering hurdles that are relevant to using functional fibers and e-textiles for operating at disparate scales—from microns to kilometers. We focus in particular on leveraging the unique material properties of a textile and the miniaturization of electronic devices in concert with the revolution in mass-manufacturing and digital fabrication technologies used to customize the device at the level of polymer, fiber, fabric, three-dimensional form, and system. We also offer a personal perspective on interdisciplinary collaboration between engineers, scientists, designers, and manufacturers for tackling some of the challenges in scaling and translation of electronic textiles.

Today, we have up to 39 000 km long deep-sea optical fibers supporting communication between four continents, and we have deployed up to 30-km-long electrodynamic tethers on orbit around Earth to harvest power from the magnetosphere. We have developed hundred micron-scale multisensory neural probes and millimeter-scale sensory meshes that can be injected into the body, alongside mesoscale fabrics with sensing, communication, and even locomotive capabilities. Functionalized fabrics now touch the full range of scales from microns to kilometers, with active and computational capability achieved at the level of fiber, yarn, fabric, and system. We consider our current place on the roadmap toward realizing an *electronic textile gaia* in which the living, nonliving, and increasingly the built environments operate as a single, harmonious, self-regulating organism, as imagined in Figure 1.

The textile has achieved ubiquity for its manufacturing scalability and myriad beneficial properties—protection, three-axis conformability, abrasion resilience, tensile strength, heat retention, high packing density, and aesthetic and cultural appeal all serve to motivate adoption of this material form.

While most textiles have remained electrically passive, one may still claim that computational textiles had an early start—the Apollo spacecraft guidance and control software developed in the 1960s at MIT was stored in a woven substrate called core rope memory.

Around the same time, a company called Woven Electronics was spawned to develop fabric circuit board prototypes that were evidently well ahead of their time. For a fleeting moment in these early days of printed circuit board (PCB) manufacturing, woven fabric circuits and core rope memory were competitive with silicon semiconductor technology.

Early fabric-based electronics hint at deep links between manufacturing processes used in the textile and electronics industries that in some cases continue into the present era: dies draw down both electrical wires and fibers, lithography, and screen-printing

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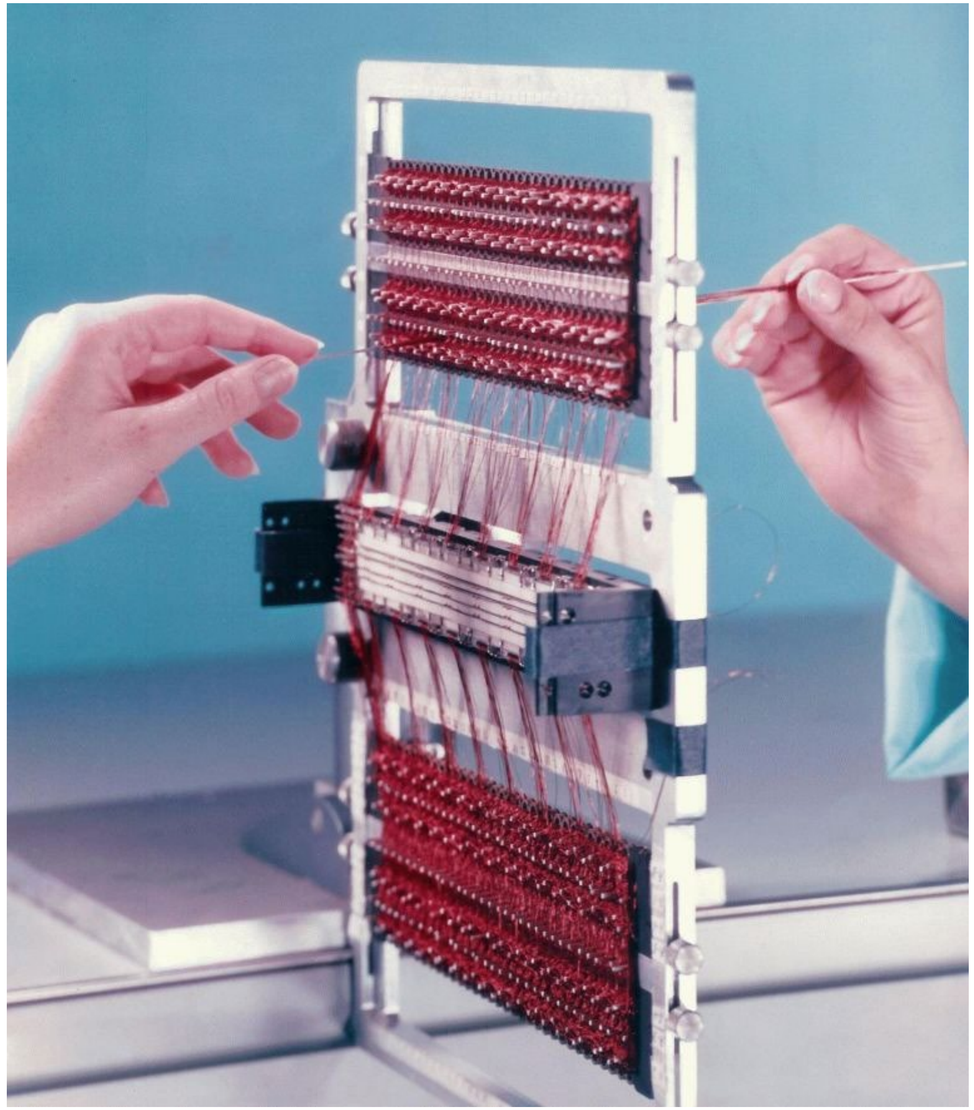
Date of publication 8 June 2021; date of current version 30 July 2021.

Textiles and Computation

Jacquard Loom (1700)



Core-rope Memory, MIT Project Apollo (1972)

Textiles and Computation

Textile Culture, Materials, and Technology


Flax - linen


Sheep wool

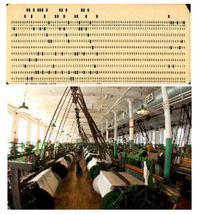

Silk

8000 BC

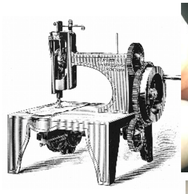
3000 BC


Needle knitting
Socks

200 BC


Punched cards
Industrial weaving
Hand warp knitting

1700

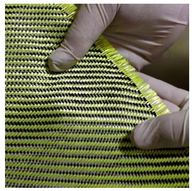

Sewing machine

1830


Cellulose
Rayon


Nylon
Polyester

1950


Spandex
Kevlar


3D Knitting
Whole-garment

1995


CNC-CAD
machines

2000


Kniterate

2015

5000 BC


Cotton

2000 BC



Linen cloth production
Nalebindiing

500 600


Spinning wheel


Batik resist-wax

1500


Hand-operated
weft knitting

1800

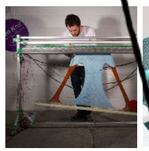

Jacquard weaving
Machine

1900

Automated weaving loom
Flatbed knitting machine

1980





3D Printing

2013

Digital weaving (TC2)
OpenKnit

Jacquard weaving
Machine

1800


Turing machine

1930


Douglas GUI

1964

Mobile phone

1980

Virtual Assistant
Wearables

2010

Computing Devices

1947

Shockley transistor

1977

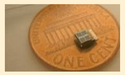
PC

2000

Smart phone

Smart Dust





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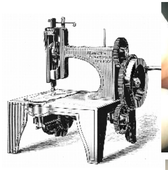

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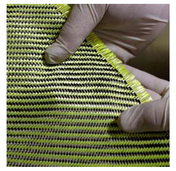

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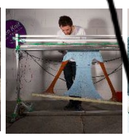

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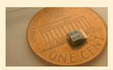


Gold leaves and gold threads
In Songket textiles

700-1000

Heated glove and blanket

1910

Core rope memory

1960

Media Lab Jacket

2000

2010

Functional/electronic fibers

Computational Materials

1913

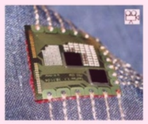
Optical fiber communication

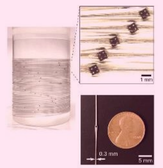
1977

Conductive polymer

2005

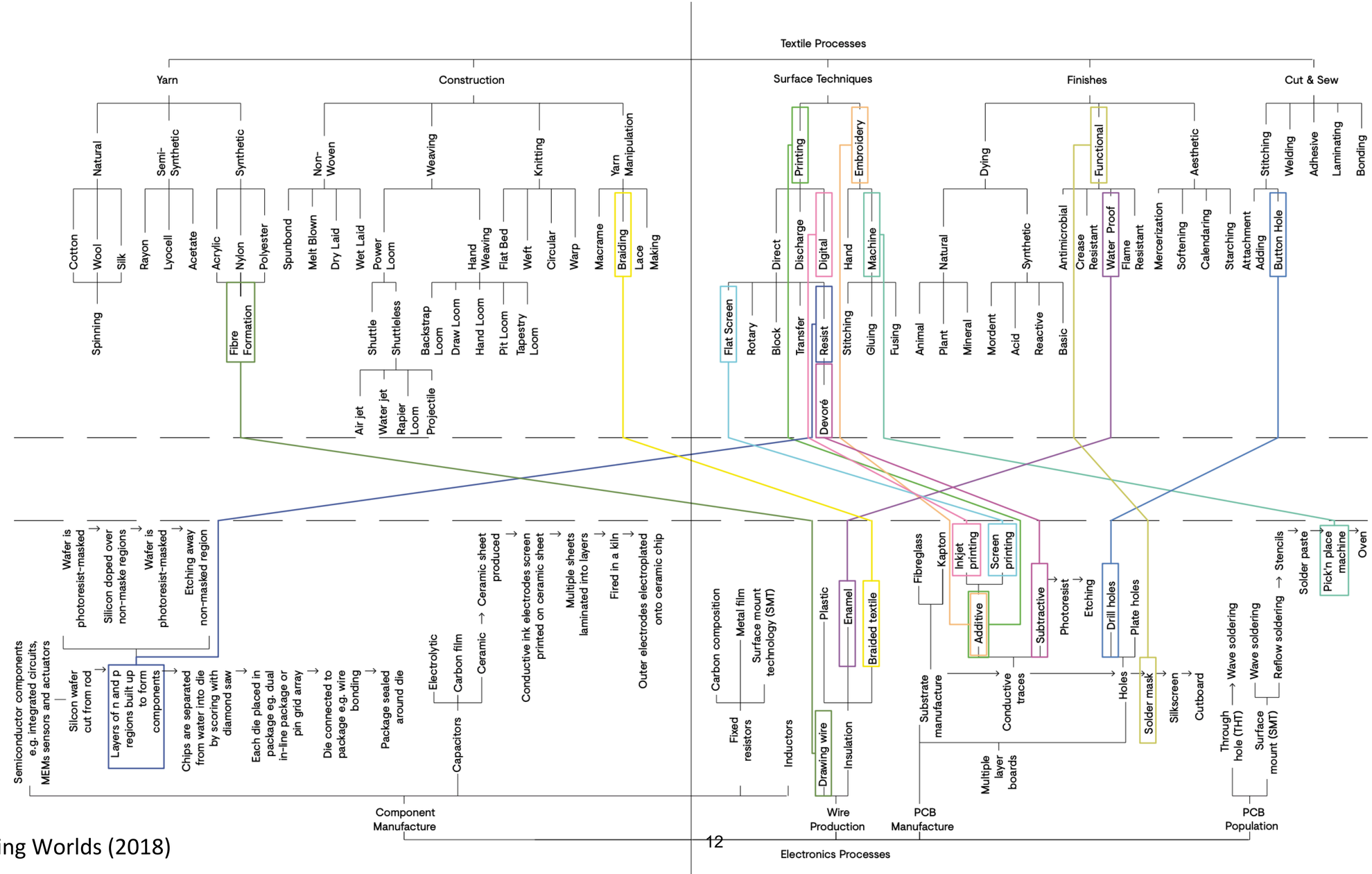
System-on-textile



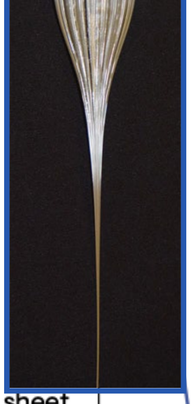


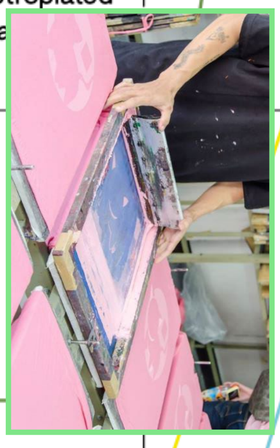
The Future

Industrial *Cross-Polination* Map (Textiles x Electronics)



Kurbak, E. Stitching Worlds (2018)





Ceramic → Ceramic sheet produced

Conductive ink electrodes screen printed on ceramic sheet

Multiple sheets laminated into layers

Fired in a kiln

Outer electrodes electroplated onto cera

Electrolytic

Carbon film

Carbon composition

Metal film

Surface mount technology (SMT)

Plastic

Enamel

Braided textile

Fibreglass

Kapton

Additive

Inkjet printing

Screen printing

Subtractive

Photoresist

Etching

Drill holes

Plate holes

Holes

mask

screen

board

Wave soldering

Wave soldering

Reflow soldering → Stencils

Solder paste

Pick'n place machine

Oven

Air jet

Water jet

Rapier Loom

Projectile

Shuttle

Shuttleless

Backstrap Loom

Draw Loom

nd Loom

Loom

estry

om

Dry Laid

Wet Laid

Non-Woven

Power Loom

Hand Weaving

Weaving

Flat Bed

Weft

Circular

Warp

Knitting

Macrame

Braiding

Lace Making

Yarn Manipulation

Flat Screen

Rotary

Block

Transfer

Devoré

Resist

Direct

Discharge

Digital

Printing

Stitching

Gluing

Fusing

Hand

Machine

Embroidery

Animal

Plant

Mineral

Natural

Mordent

Acid

Reactive

Basic

Synthetic

Dying

Antimicrobial

Crease Resistant

Water Proof

Flame Resistant

Functional

Mercerization

Softening

Calendaring

Starching

Aesthetic

Attachment Adding

Button Hole

Stitching

Welding

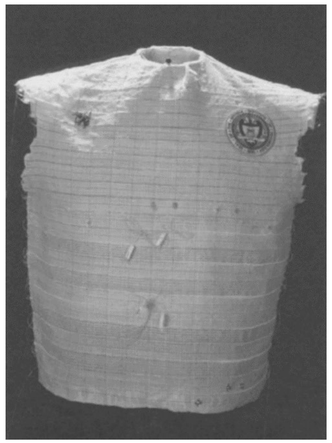
Adhesive

Laminating

Bonding

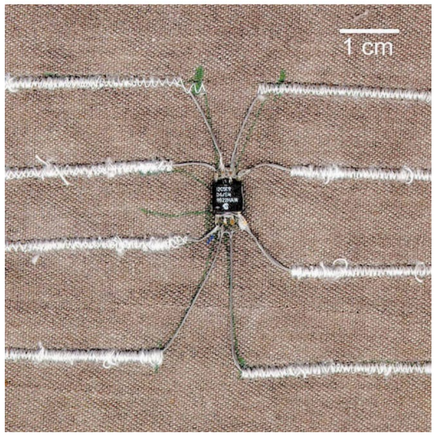
E-textiles: hand-crafted at the fabric-level

Musical Jacket
Orth, M *et al*., SIGGRAPH (1998).

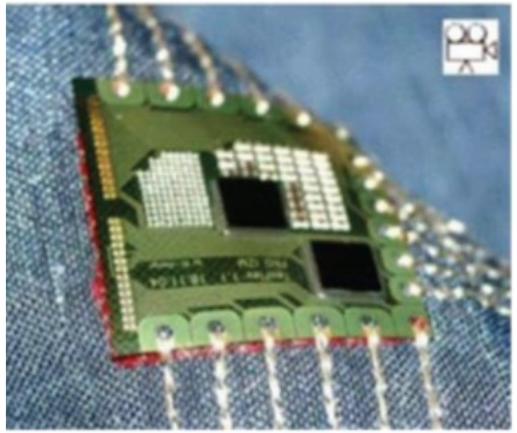


Wearable Motherboard
Gopalsamy, M *et al*., (1999)

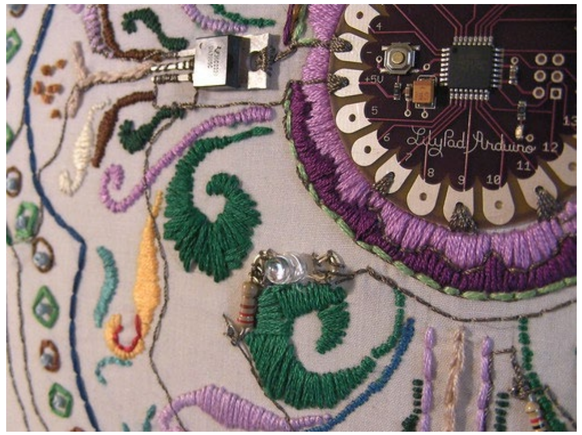
Musical Balls
Weinberg, G *et al*., CHI (2000).



E-broidery: textile-based computing
Post, E.R. *et al*., IBM Sys (2000).



Fully-integrated EKG Shirt
Linz *et al*., BSN (2006).

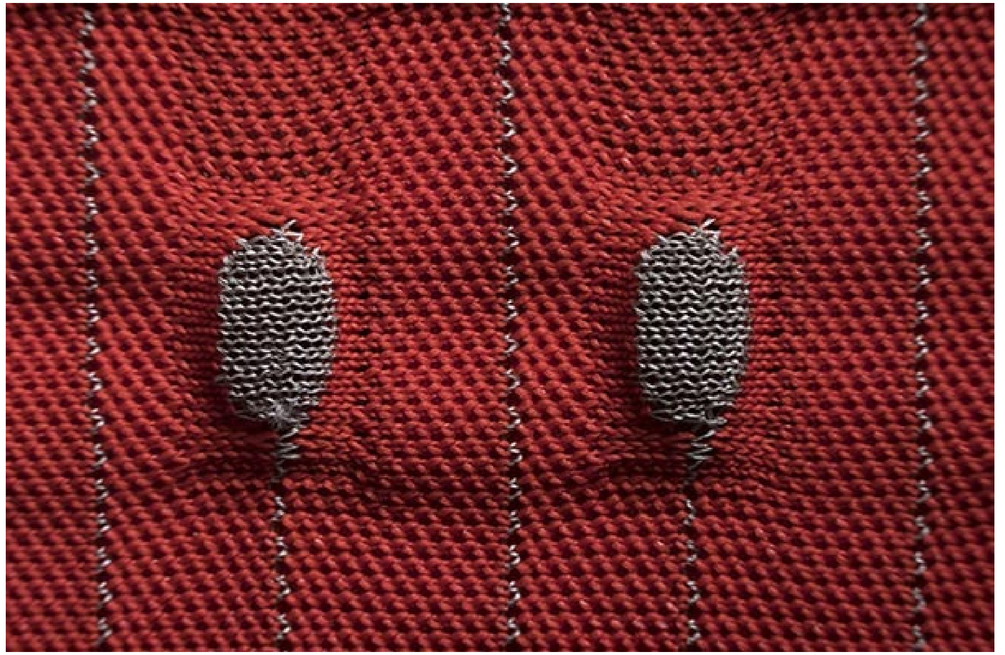


Fabric PCBS: e-textile craft
Buechley and Eisenberg, UbiComp (2009).

FabricKeyboard: Multi-modal E-textile Musical Interface
Wicaksono and Paradiso, NIME (2017).

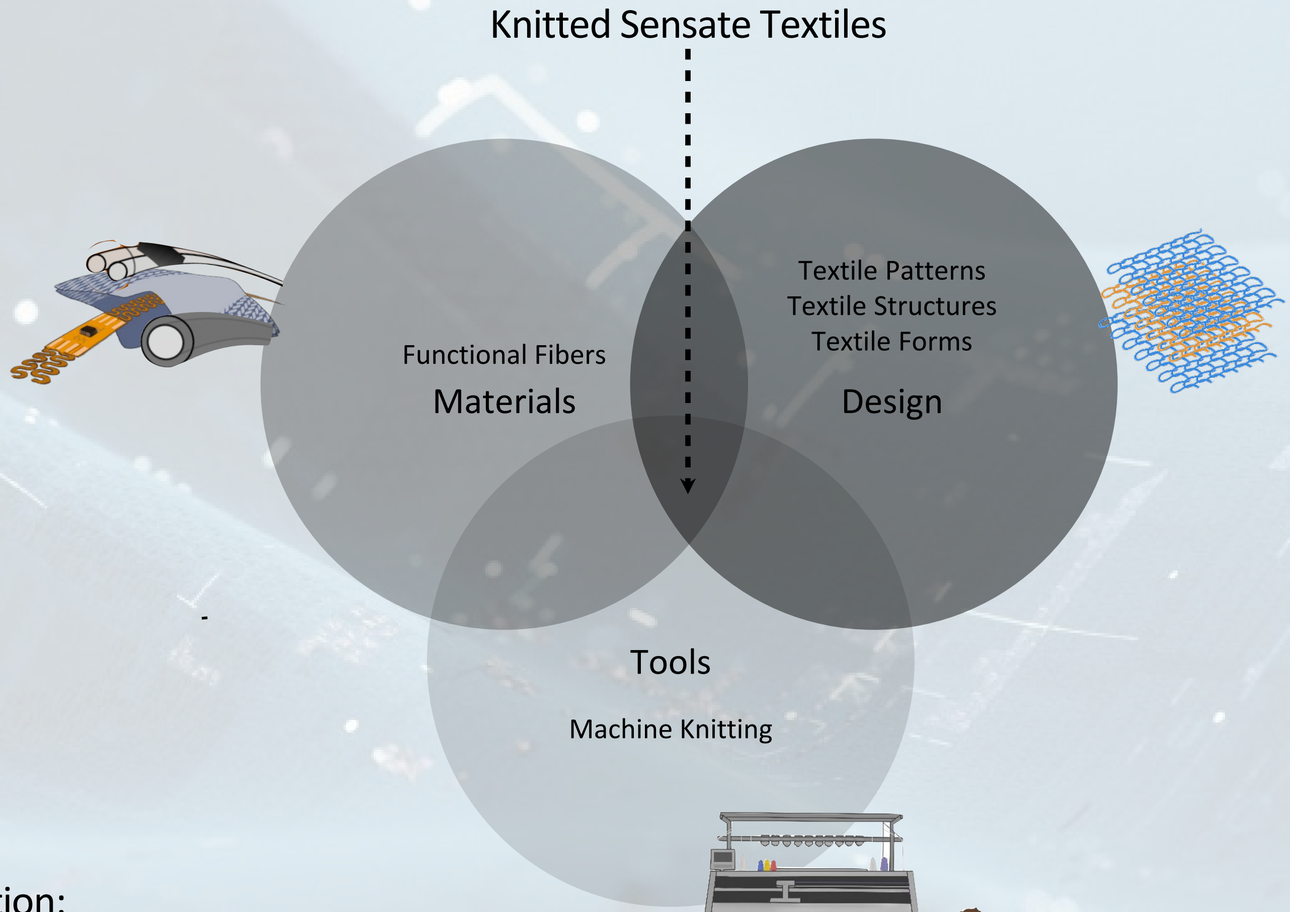
E-textiles: industrial manufacturing from the yarn

Project Jacquard
Poupryev, I *et al.* ACM CHI (2016)



SensorKnit
Ou et *al.* 3DP (2019)

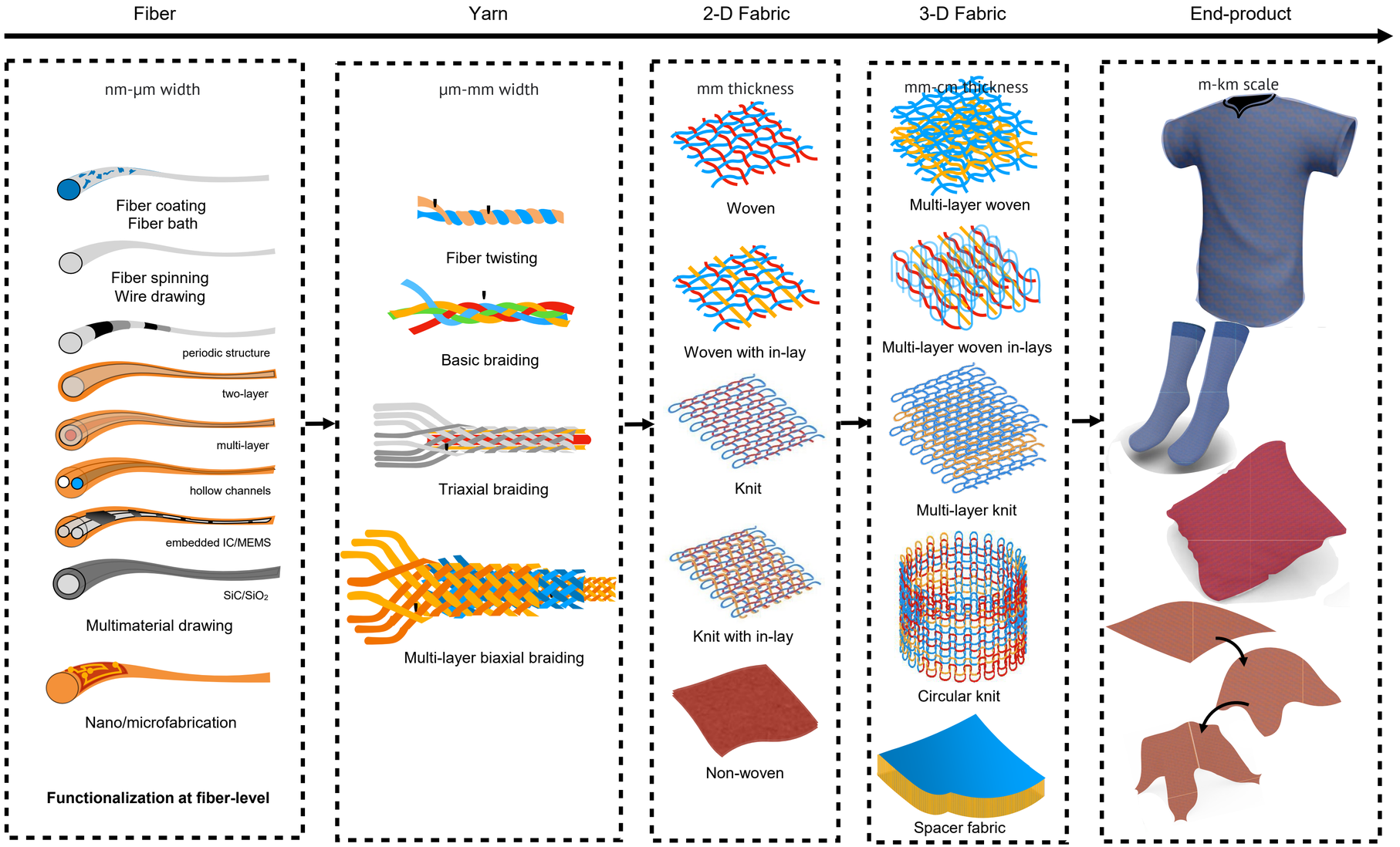
Digital Knitting of Sensate Textiles



Projects:
KnittedKeyboard
3DKnITS
Tapis Magique
Living Knitwork Pavilion

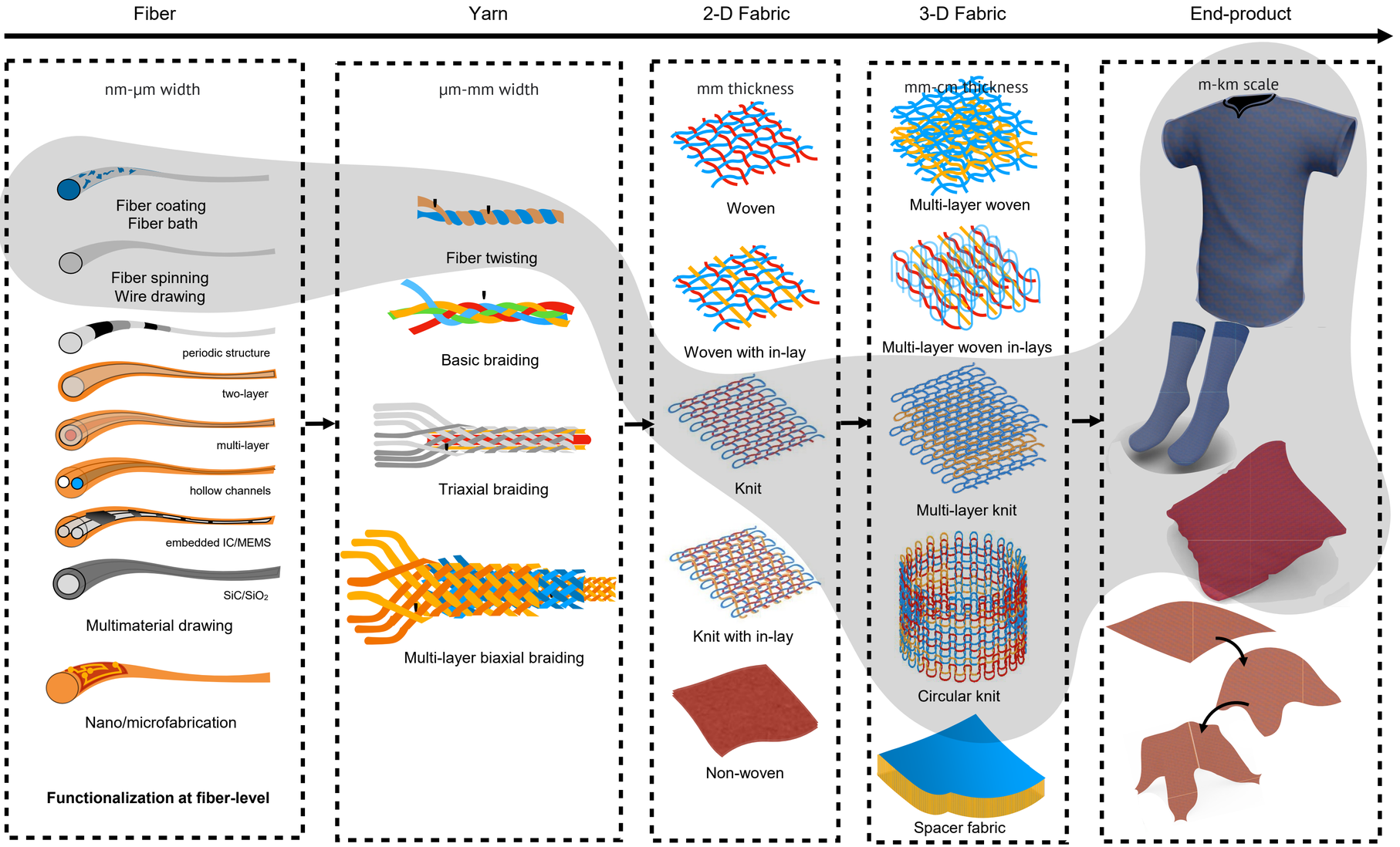
Contribution:
Design methodology and framework
Project artifact across scales
Hardware system development
Application space

E-textiles: hierarchical architecture

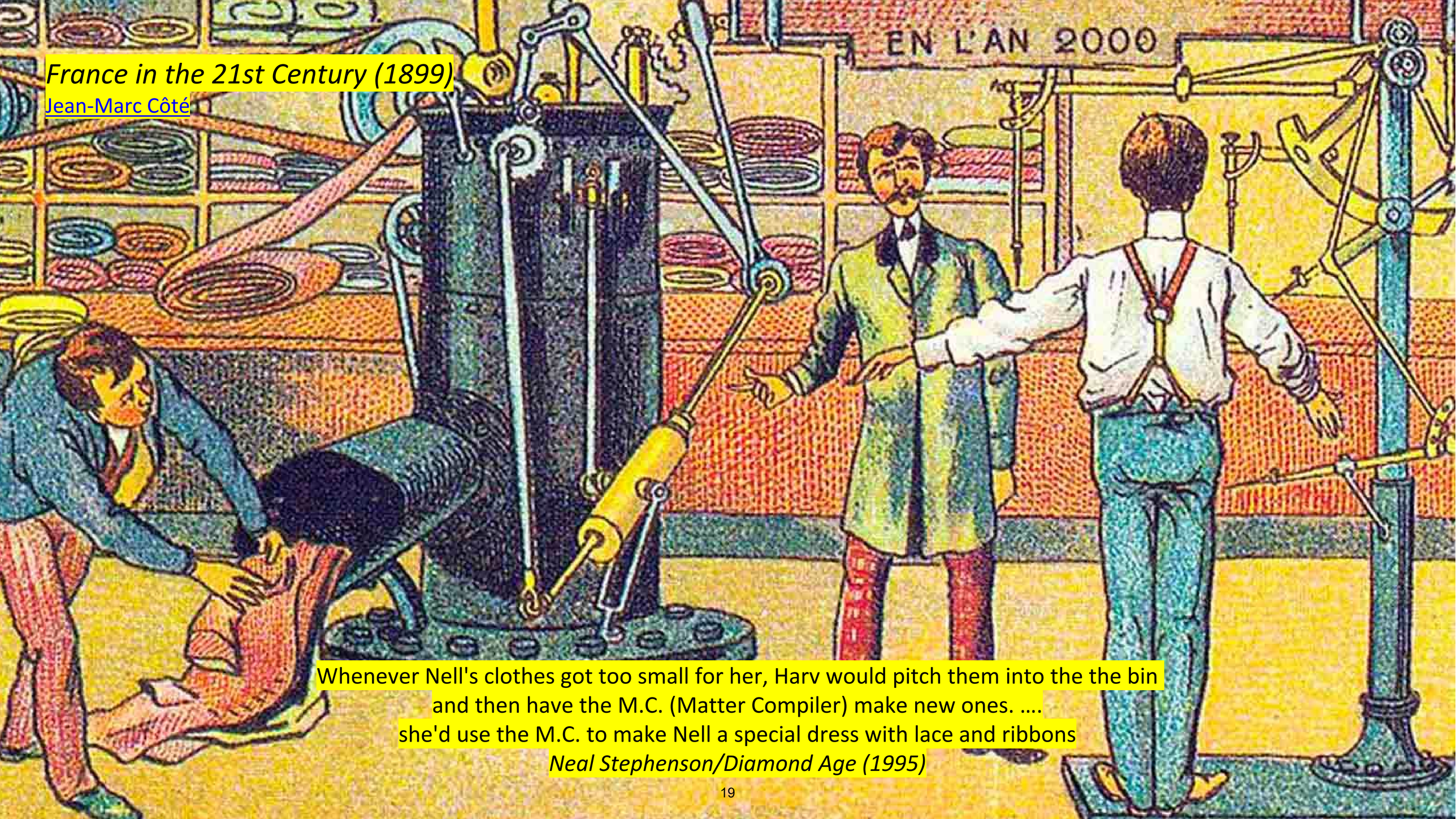


Wicaksono , Cherston, and Paradiso, E-Textile Gaia, IEEE PvC (2021)

E-textiles: hierarchical architecture



Wicaksono , Cherston, and Paradiso, E-Textile Gaia, IEEE PvC (2021)

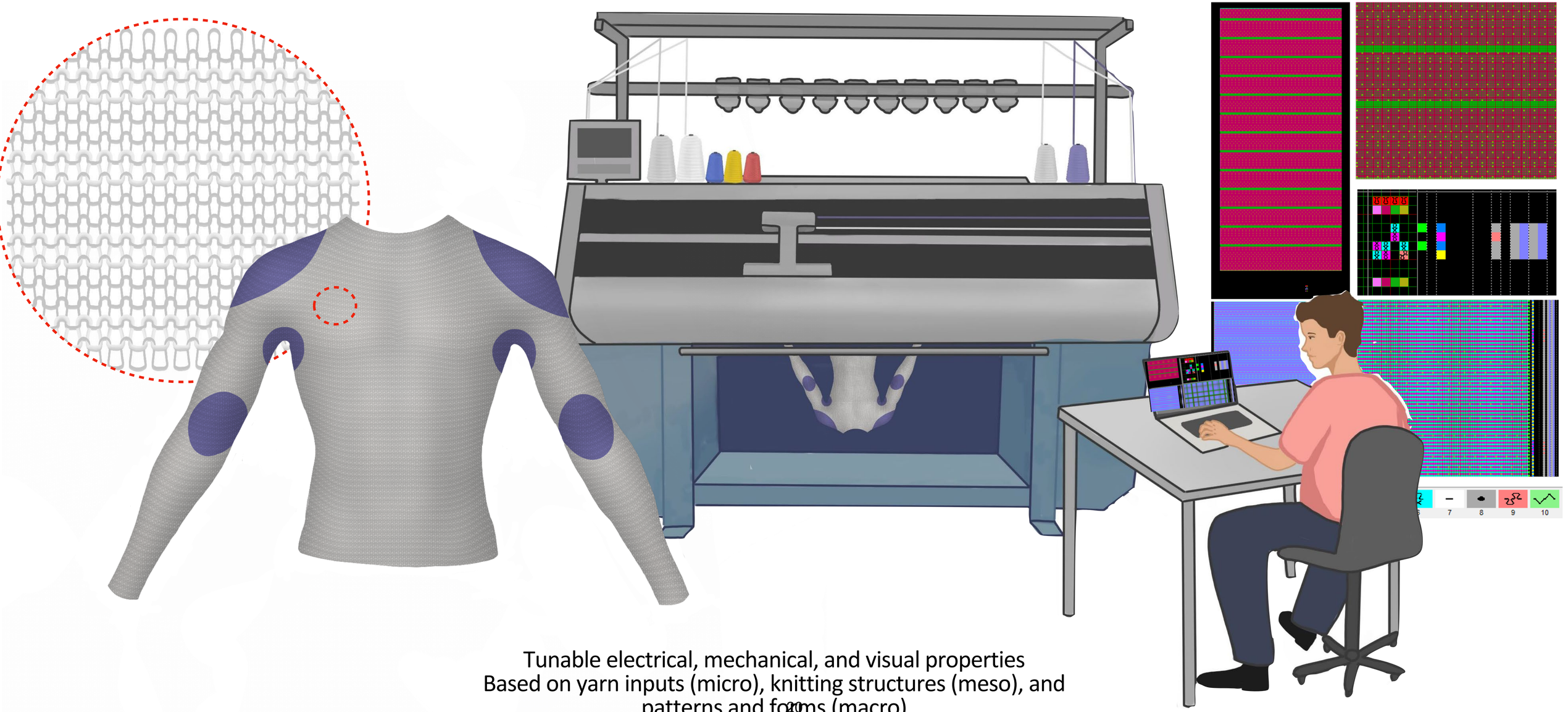


France in the 21st Century (1899)

Jean-Marc Côté

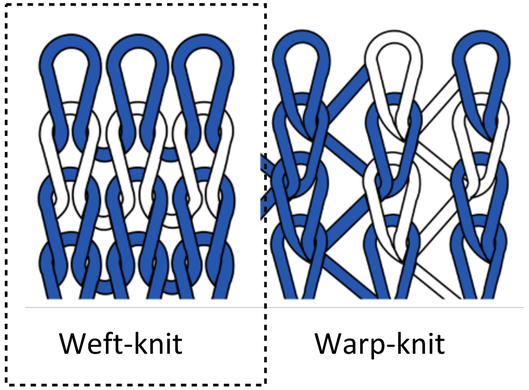
Whenever Nell's clothes got too small for her, Harv would pitch them into the the bin and then have the M.C. (Matter Compiler) make new ones. ….
she'd use the M.C. to make Nell a special dress with lace and ribbons
Neal Stephenson/Diamond Age (1995)

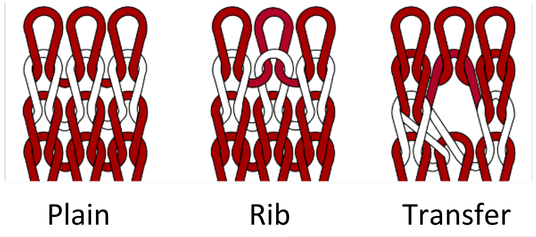
Digital machine knitting - a versatile fabrication process

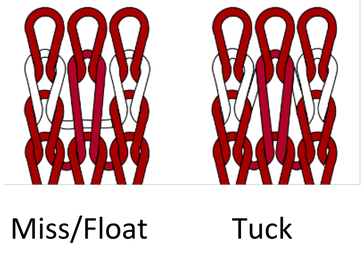


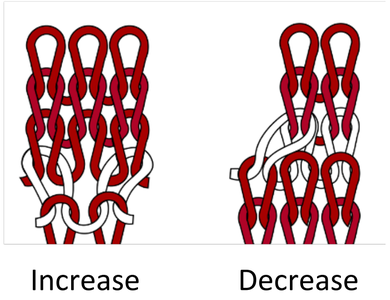
Tunable electrical, mechanical, and visual properties
Based on yarn inputs (micro), knitting structures (meso), and patterns and forms (macro)

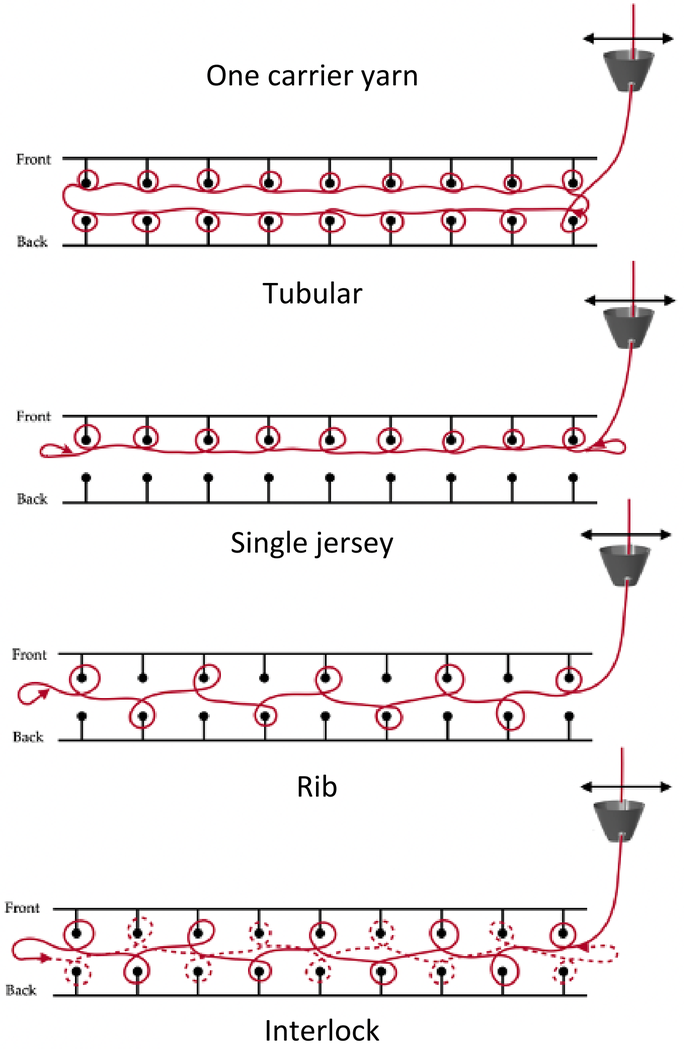
Knitting operations

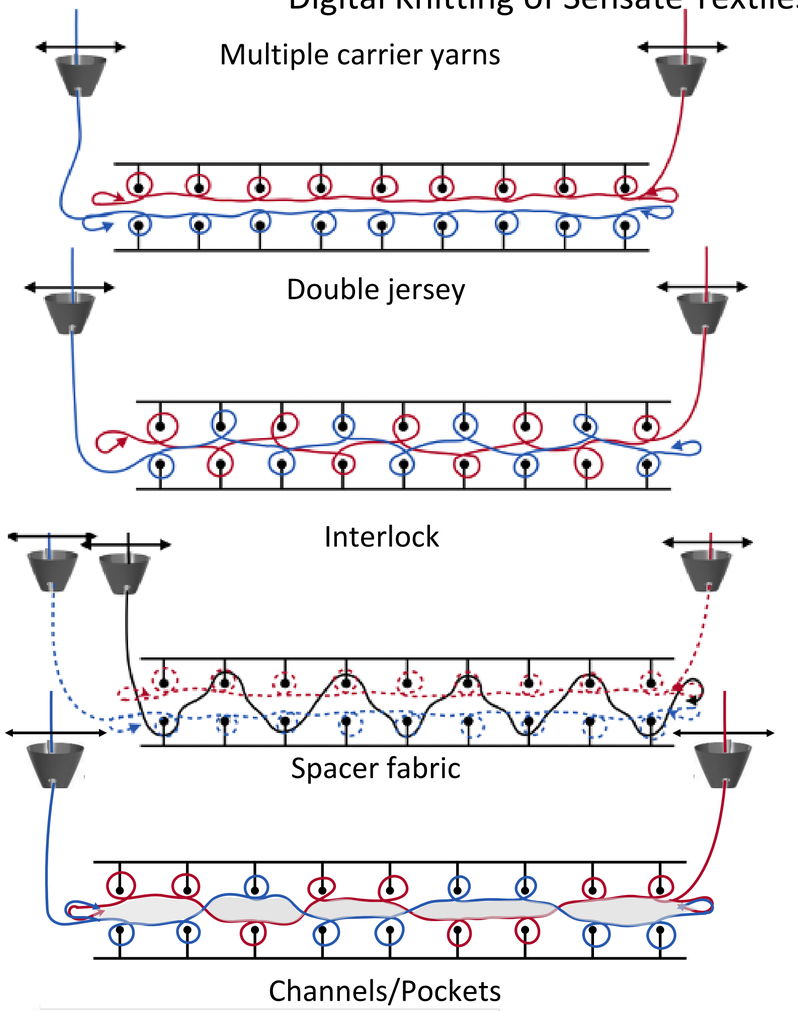


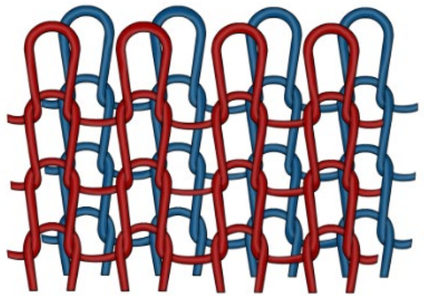


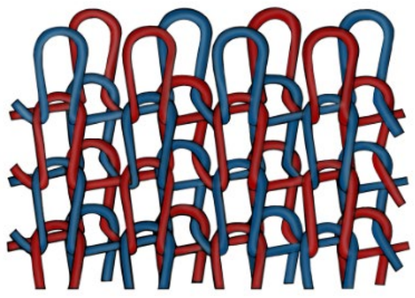




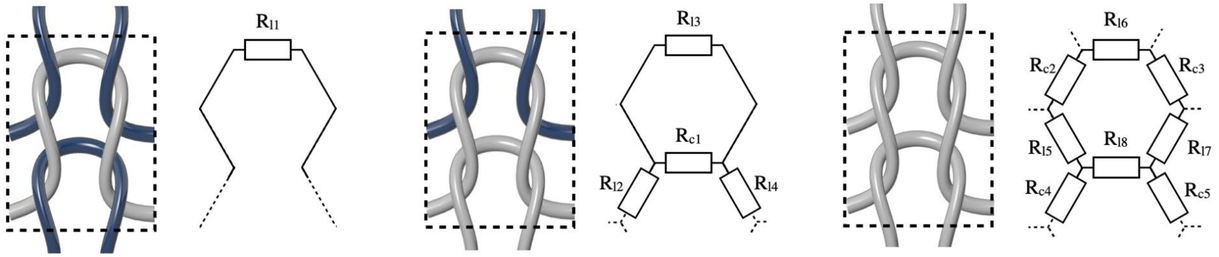






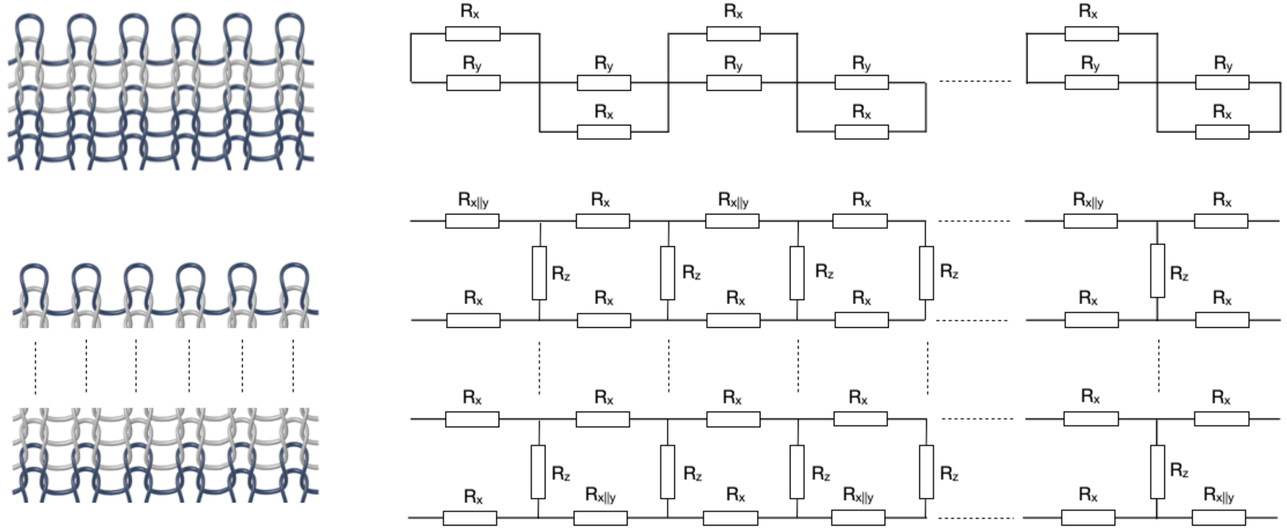


Knitted conductive yarns resistance modeling



Resistive network + signal flow theory

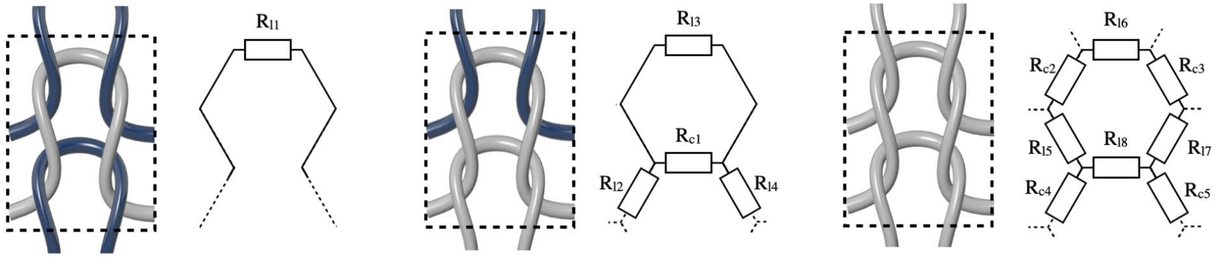
$$R_x = R_{l3} + 0.5R_c$$
$$R_y = R_{l6} + 0.5R_c$$
$$R_z = R_{l5} + 0.5R_c = R_{l7} + 0.5R_c$$

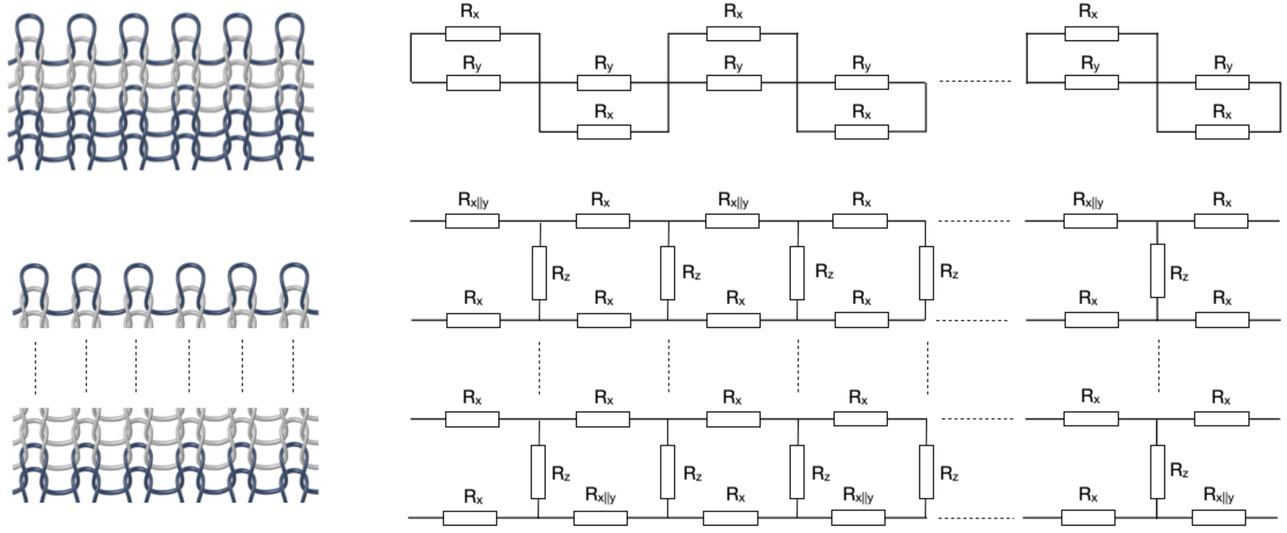


$$R_{x||y} = \frac{(kR_l^2 + 0.5(k+1)R_cR_l + 0.25R_c^2}{(k+1)R_l + R_c}$$

$$R_{total(m>2)} = \frac{2NR_x(R_x + R_{x||y})}{(M+1)R_x + (M-3)R_{x||y}}$$

Knitted conductive yarns resistance modeling





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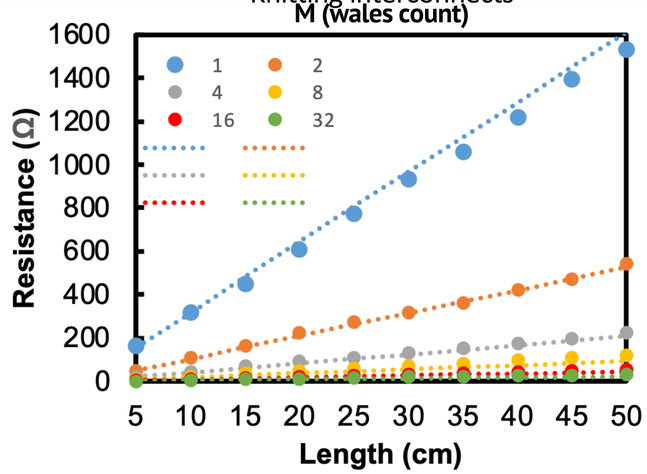
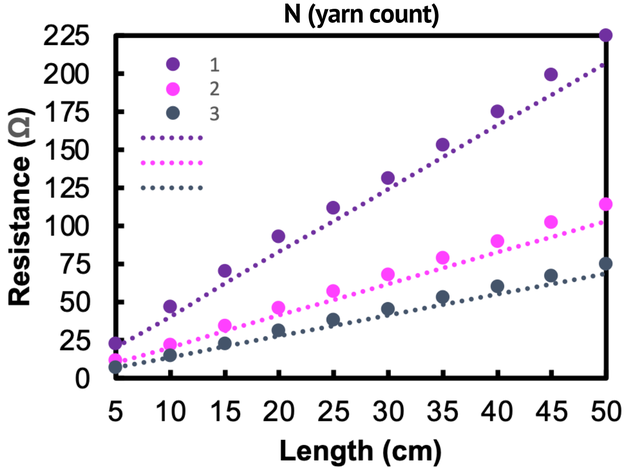
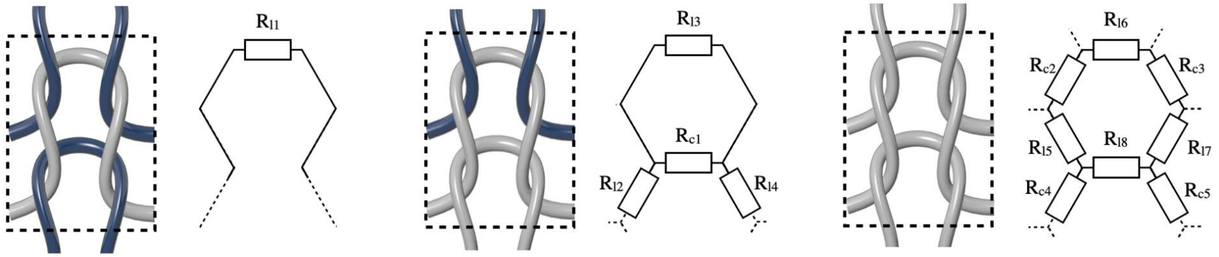
$$R_{total(m>2)} = \frac{2NR_x(R_x + R_{x||y})}{(M+1)R_x + (M-3)R_{x||y}}$$

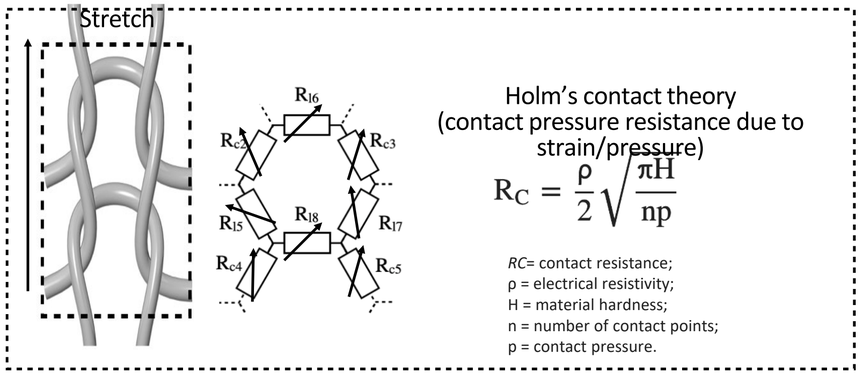
Knitting interconnects

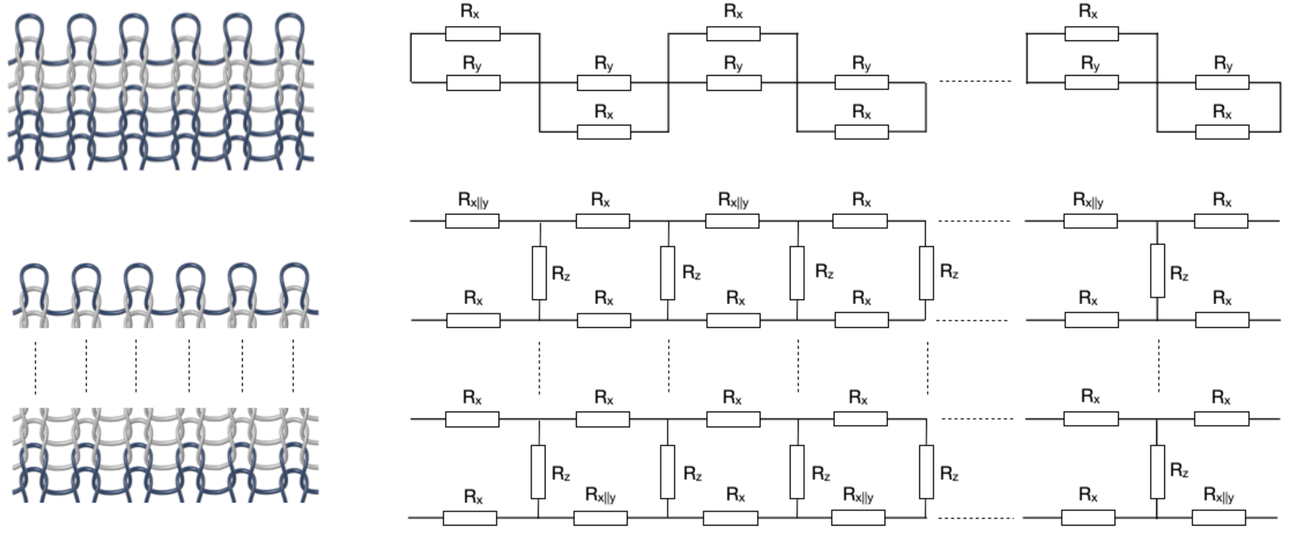


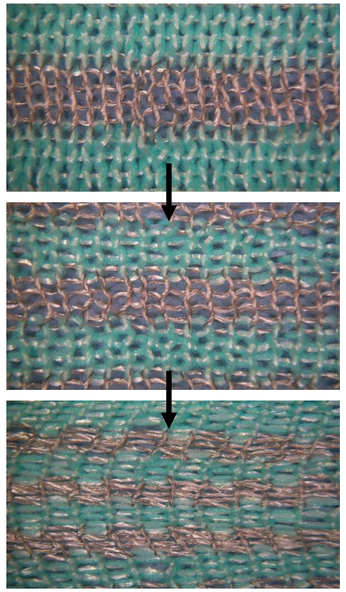


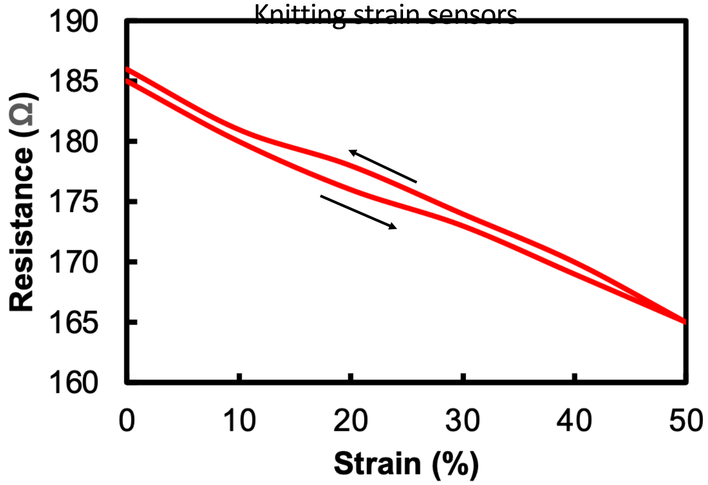
Knitted conductive yarns resistance modeling









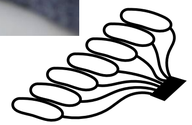


Digital Knitting of Sensate Textiles

Architecting sensate textiles across scales

Objects

60 touch + 5 stretch + 1 pressure
Capacitive and piezoresistive array
72 connections
0.15m^2 active area



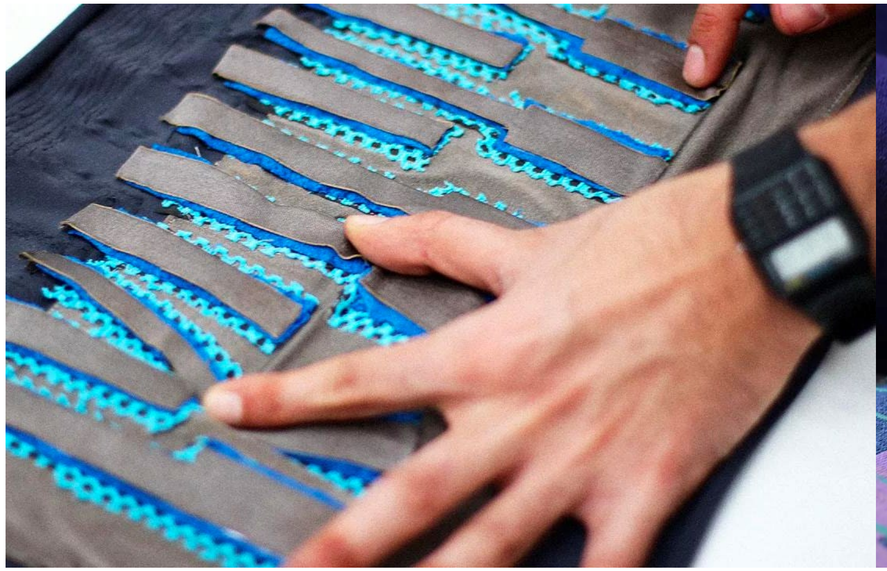
KnittedKeyboard
Musical expression

KnittedKeyboard

KnittedKeyboard

FabricKeyboard to KnittedKeyboard

From manual, to seamless and automated integration



FabricKeyboard (2017)

12 keys/1 octave

- 12 capacitive touch sensing elements,
- 12 proximity sensing elements (1 multiplexed possible)
- 12 pressure sensing elements,
- 1 stretch across the keys
- 12 electric field elements (different board)

KnittedKeyboard v1 (machine-produced, 2020)

60 keys/5 octave

- 60 capacitive touch sensing elements,
- 60 proximity sensing elements (5 multiplexed)
- 1 pressure sensing elements,
- 5 thermochromic color change (per octave)

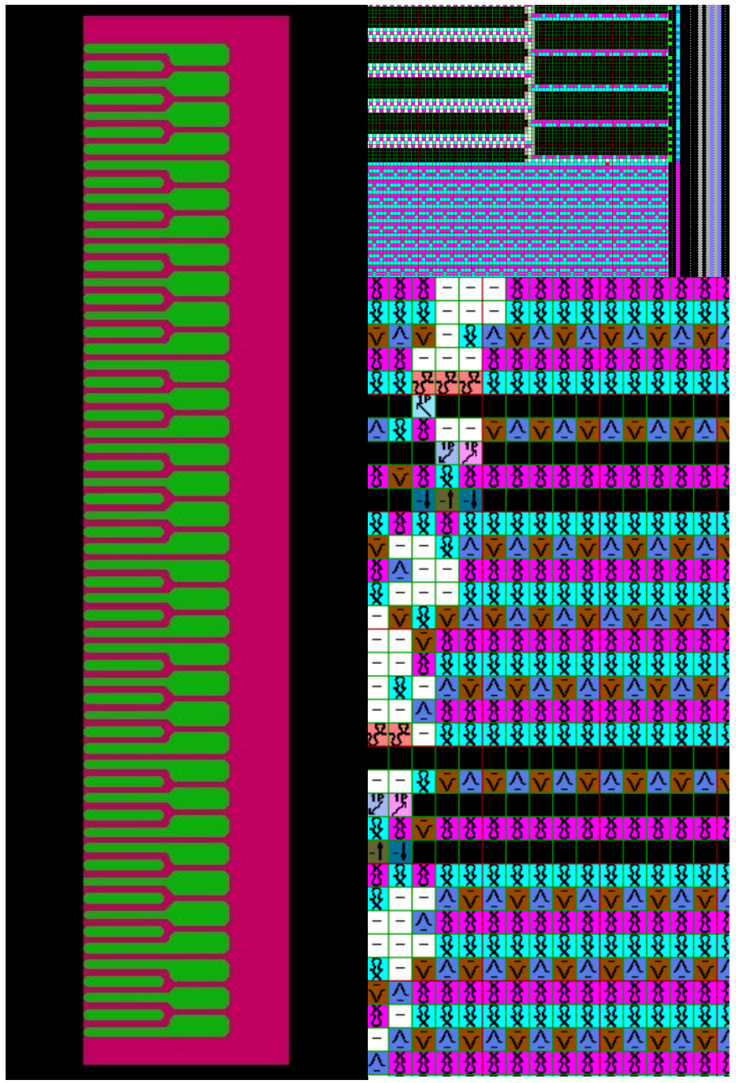
KnittedKeyboard v2 (2021, improved design)

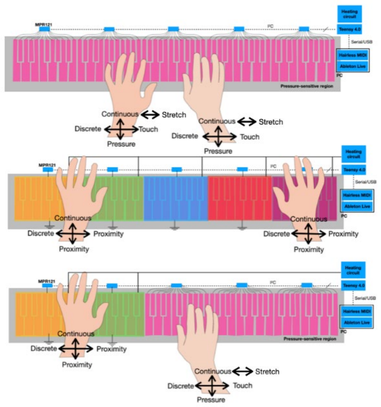
60 keys/5 octave

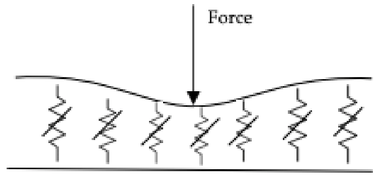
- 60 capacitive touch sensing elements,
- 60 proximity sensing elements (5 multiplexed)
- 1 pressure sensing elements,
- 1 stretch across the keys

Wicaksono and Paradiso, FabricKeyboard, NIME (2017)
Wicaksono and Paradiso, KnittedKeyboard, NIME (2020)

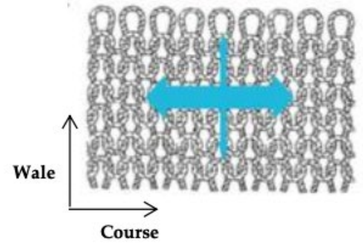
KnittedKeyboard





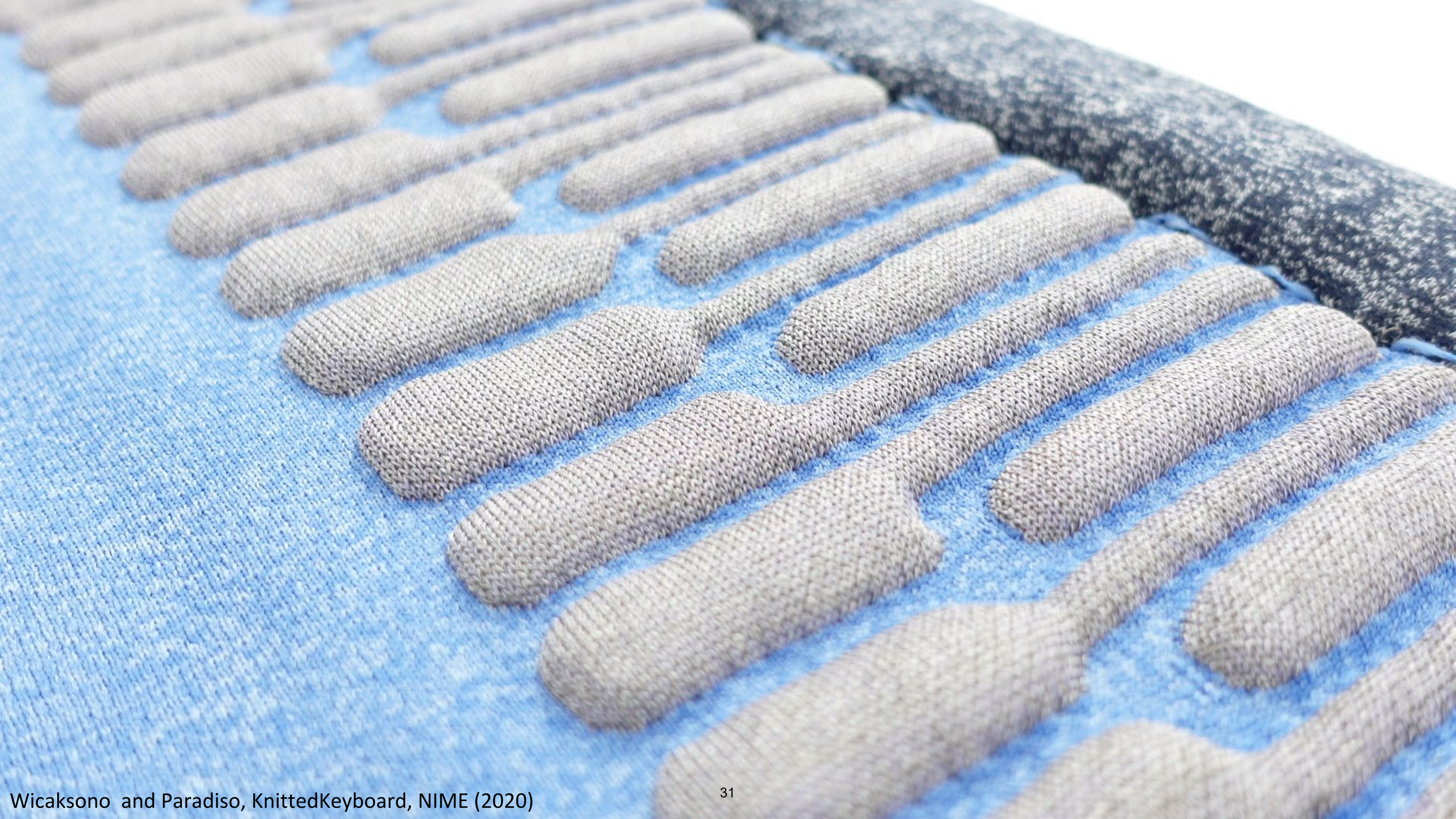


Piezoresistive pressure sensing



Piezoresistive strain sensing

Wicaksono and Paradiso, KnittedKeyboard, NIME (2020)



Wicaksono and Paradiso, KnittedKeyboard, NIME (2020)

Musician, Composer: Mike Jiang, Video: Jimmy Day

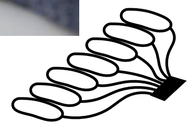
Jordan Rudess, Dream Theater

Architecting sensate textiles across scales

Objects

60 touch + 5 stretch + 1 pressure
Capacitive and piezoresistive array
72 connections

KnittedKeyboard
Musical expression

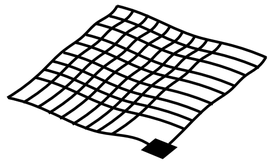


Body

12 x 8 pressure-sensing pixels
Piezoresistive matrix
20 connections

3DKnITS

Activity recognition
Biomechanics



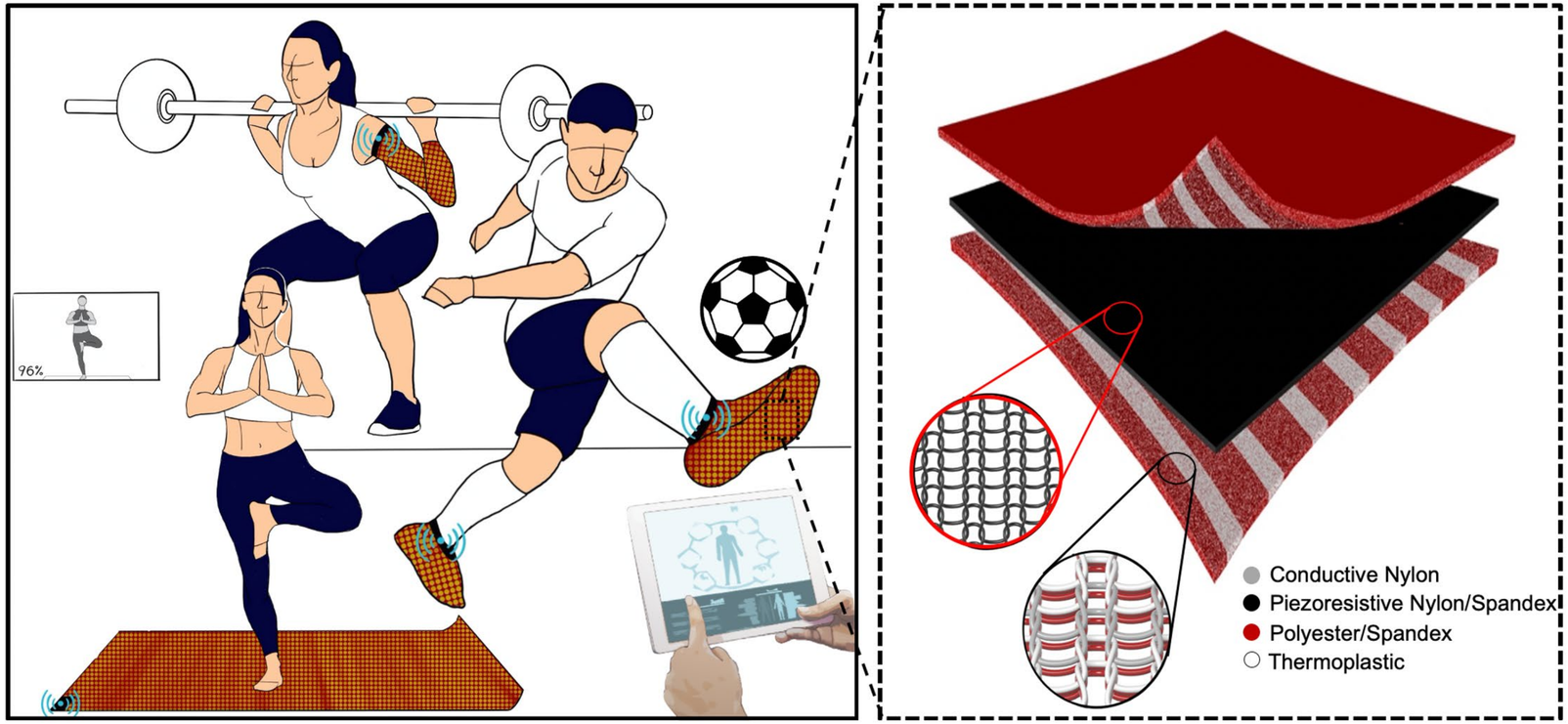
3DKnITS: 3-D Knitted Intelligent Textile Sensor

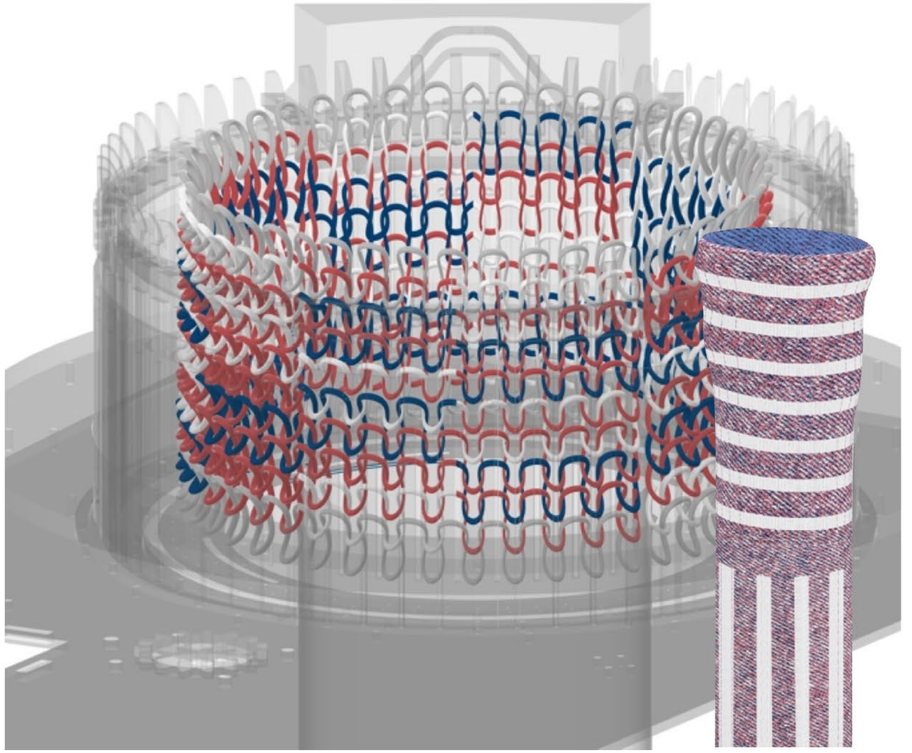
Wicaksono et al., 3DKnITS, IEEE EMBC (2022)

3DKnITS: 3-D Knitted Intelligent Textile Sensor

Wicaksono et al., 3DKnITS, IEEE EMBC (2022)

3DKnITS: 3-D Knitted Intelligent Textile Sensor

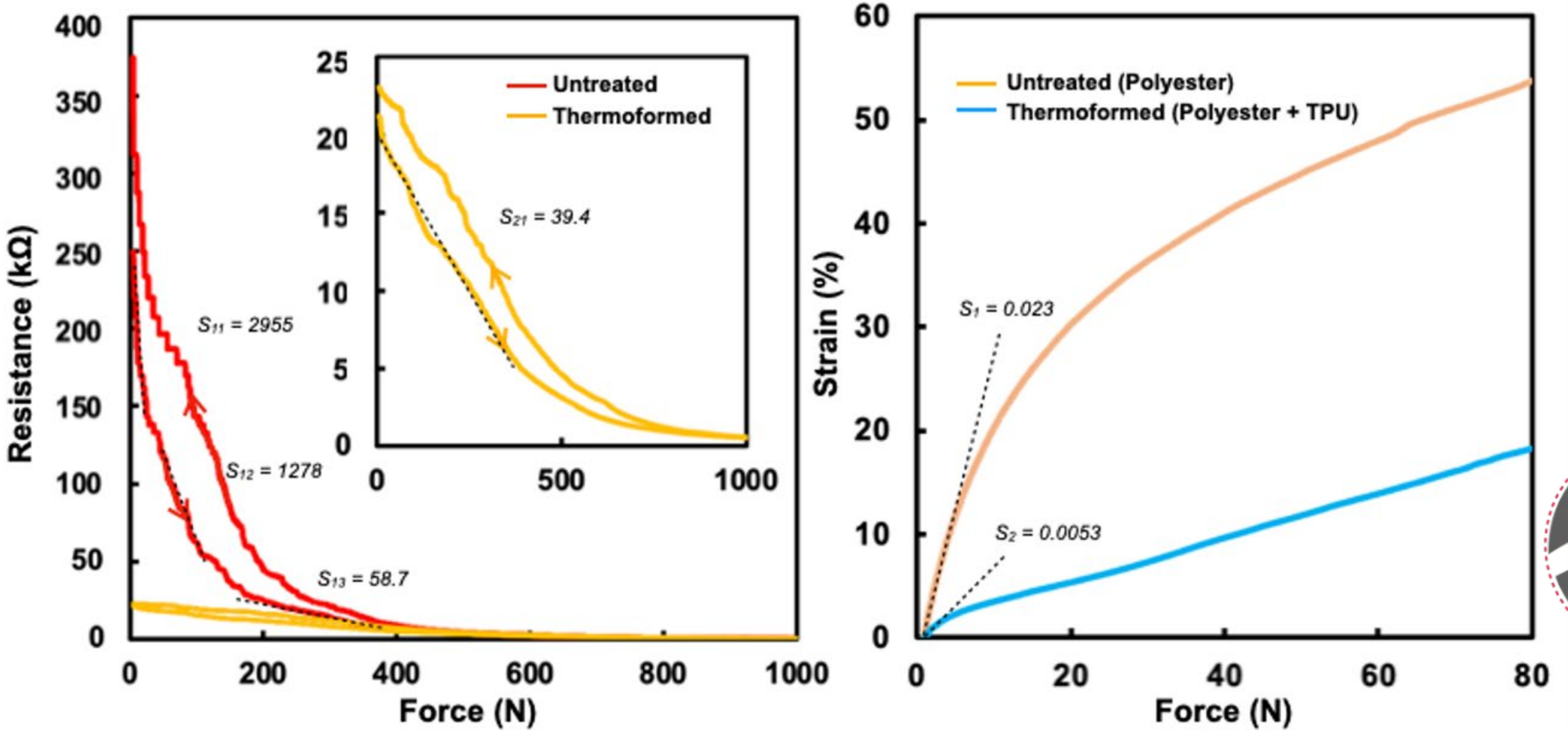




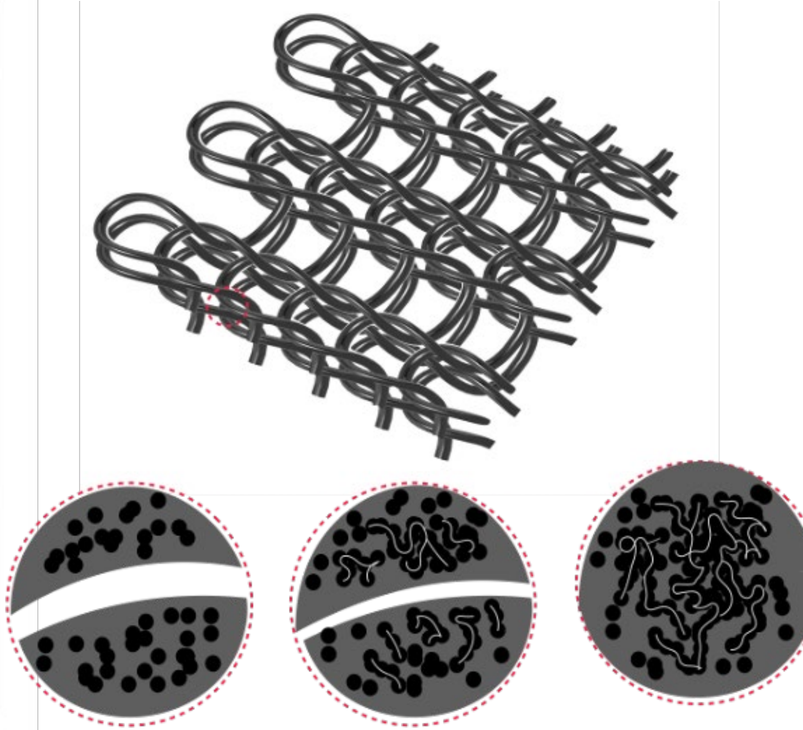
Wicaksono, Hwang, Droubi et al., 3DKnITS, IEEE EMBC (2022)

Electromechanical characterization

Designing knitted e-textile for robust pressure-sensing



Force vs resistance and stress-strain tensile characterization of both the untreated and thermoformed knit textiles.

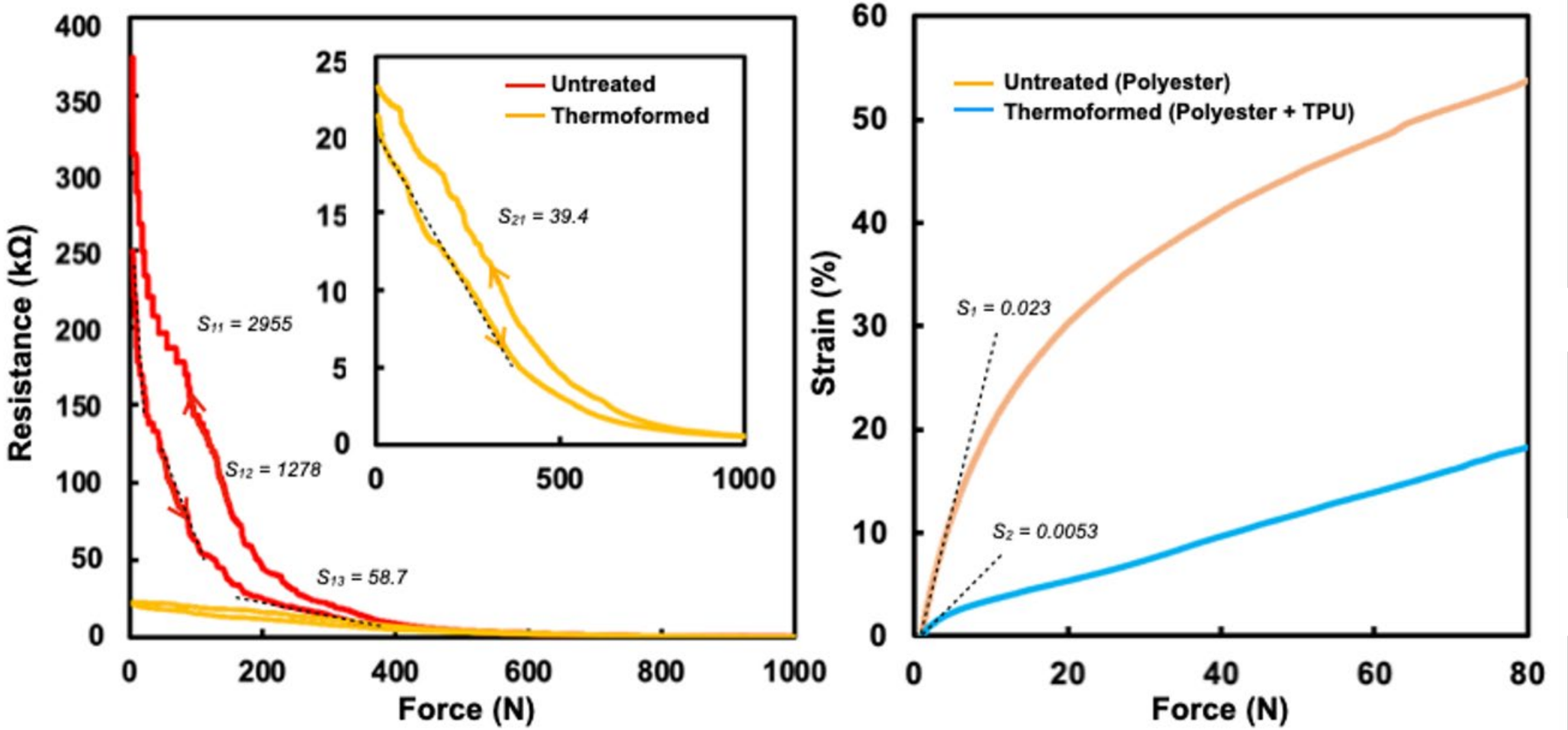


Percolation network of conductive molecules in pressure-sensitive textiles

Wicaksono, Hwang, Droubi et al., 3DKnITS, IEEE EMBC (2022)

Electromechanical characterization

Designing knitted e-textile for robust pressure-sensing



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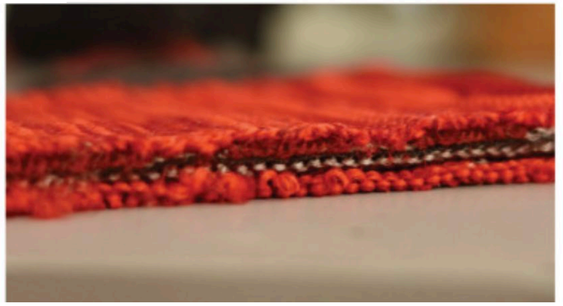
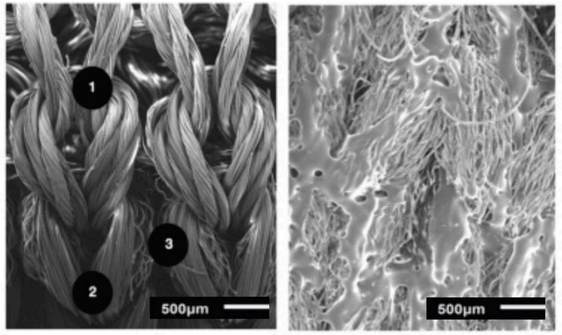


Multi-layer textiles

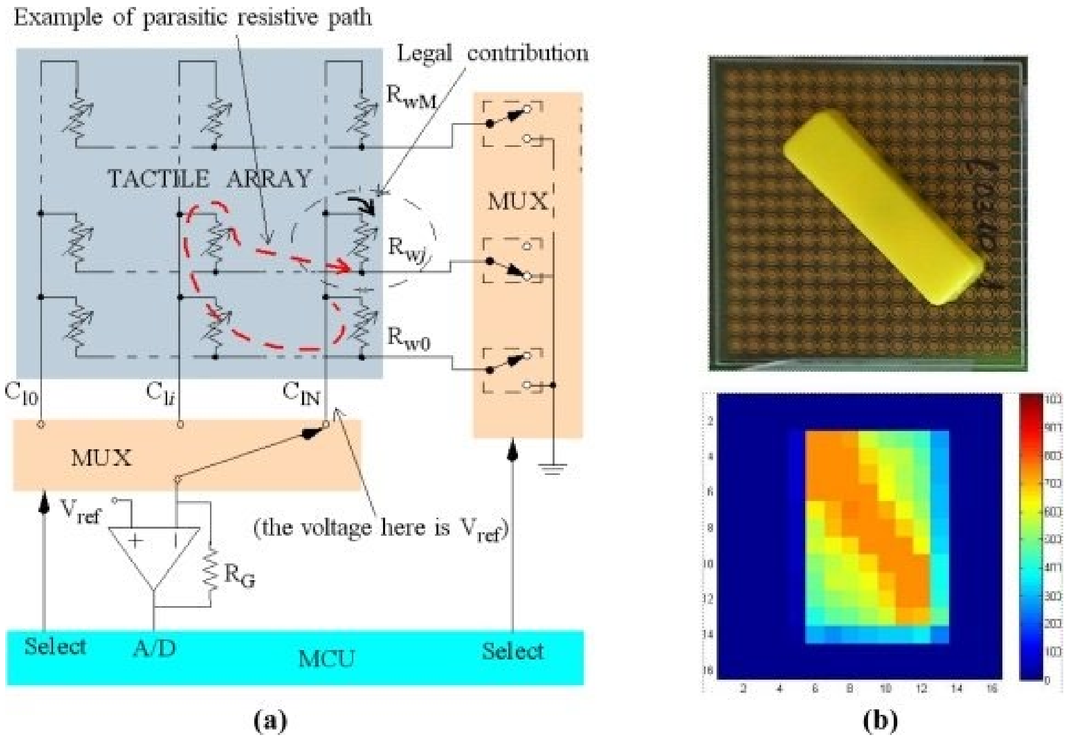


Thermoformed

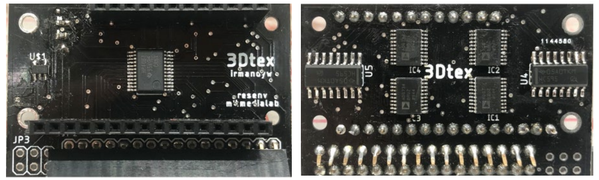
Wicaksono, Hwang, Droubi et al., 3DKnITS, IEEE EMBC (2022)

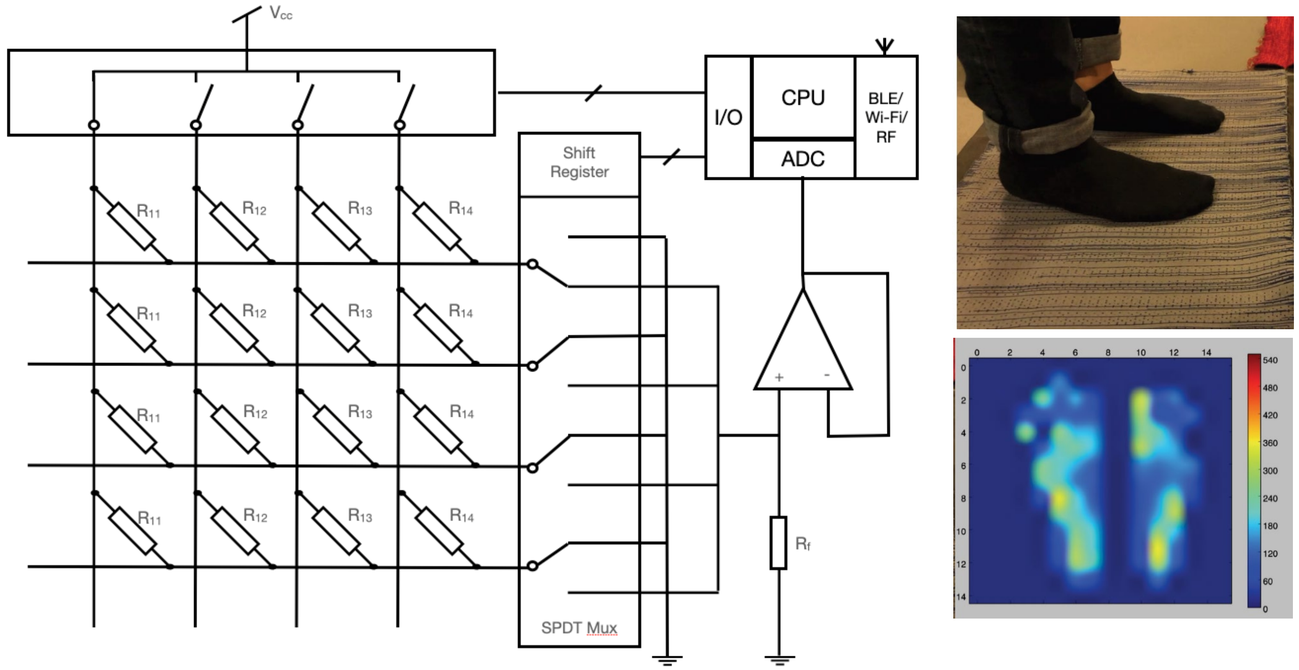
Multiplexing circuits

Designing knitted e-textile hardware for robust pressure-sensing



Vidal-Verdu et al., Sensors (2011)

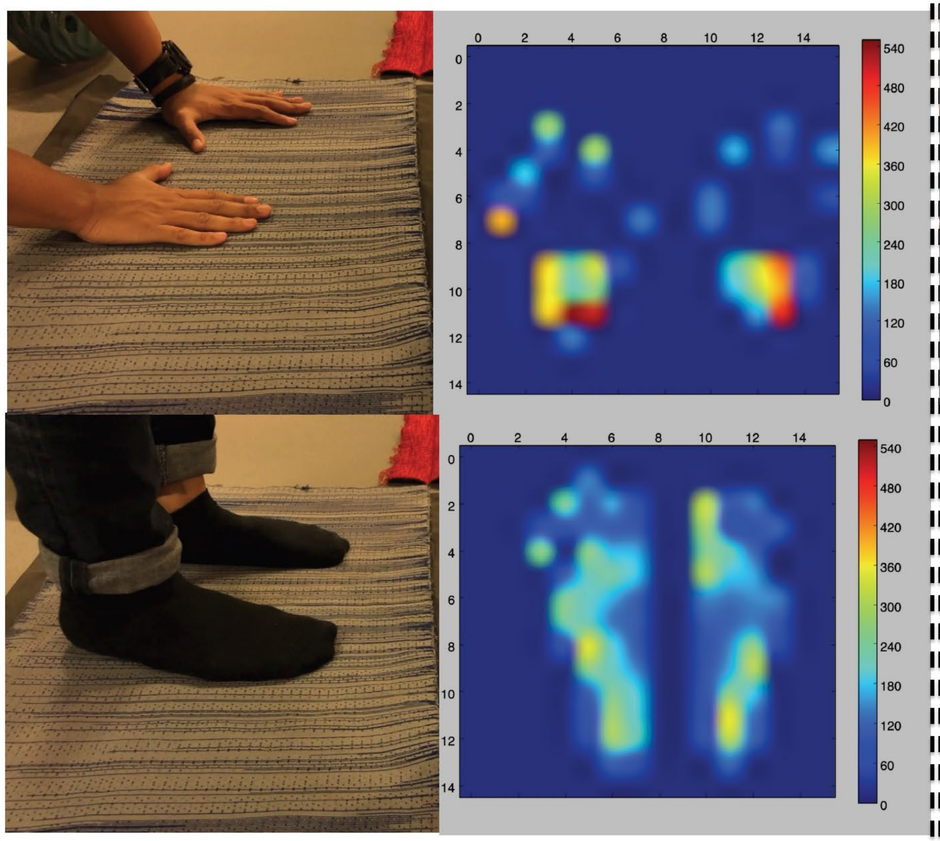




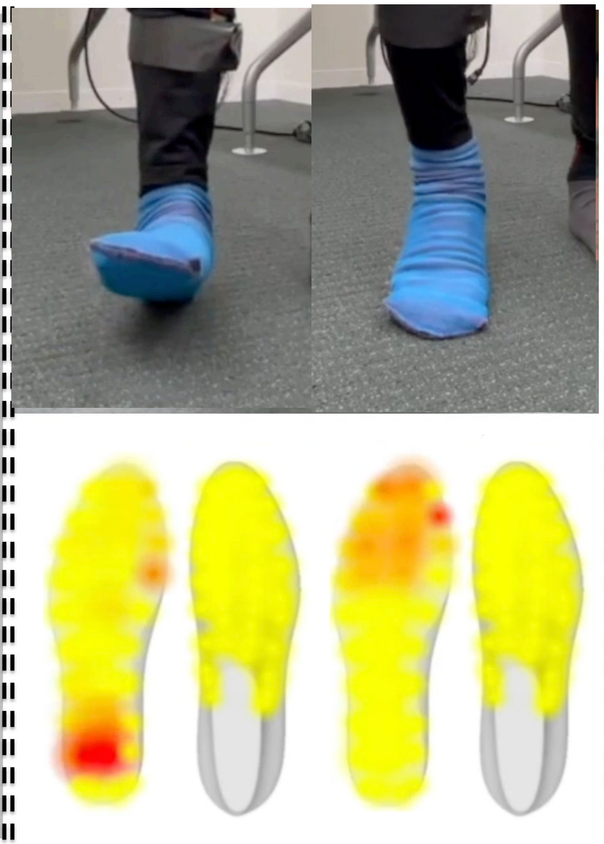
Our multiplexing circuit (16x16)

Wicaksono, Hwang, Droubi et al., 3DKnITS, IEEE EMBC (2022)

Dense spatiotemporal pressure-imaging



16x16 pressure-sensing pixel (2.5cm pitch)
256 pixels, 45x45 cm

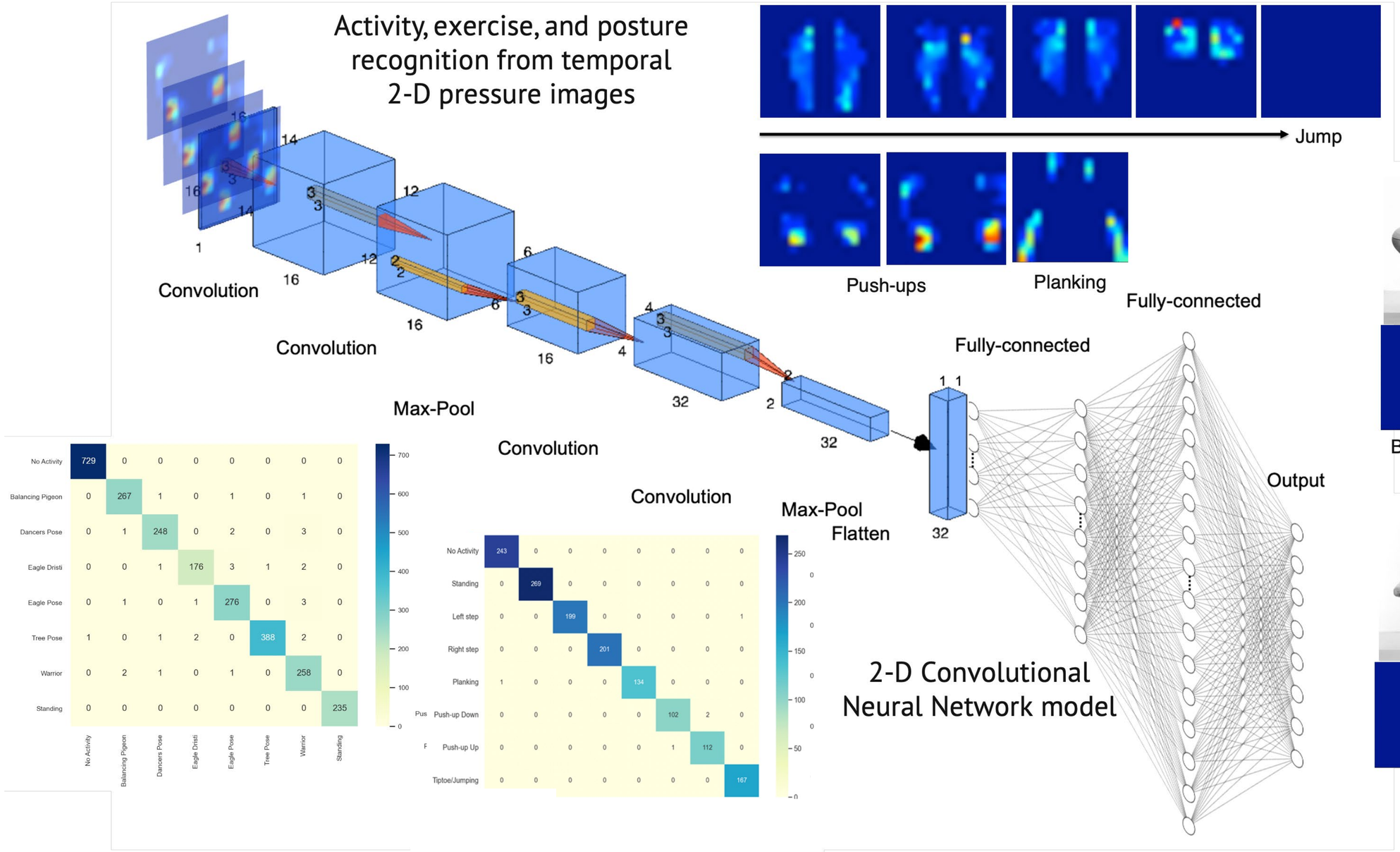


8x12 pressure-sensing pixel (2.5cm pitch)
96 pixels, 24x30 cm

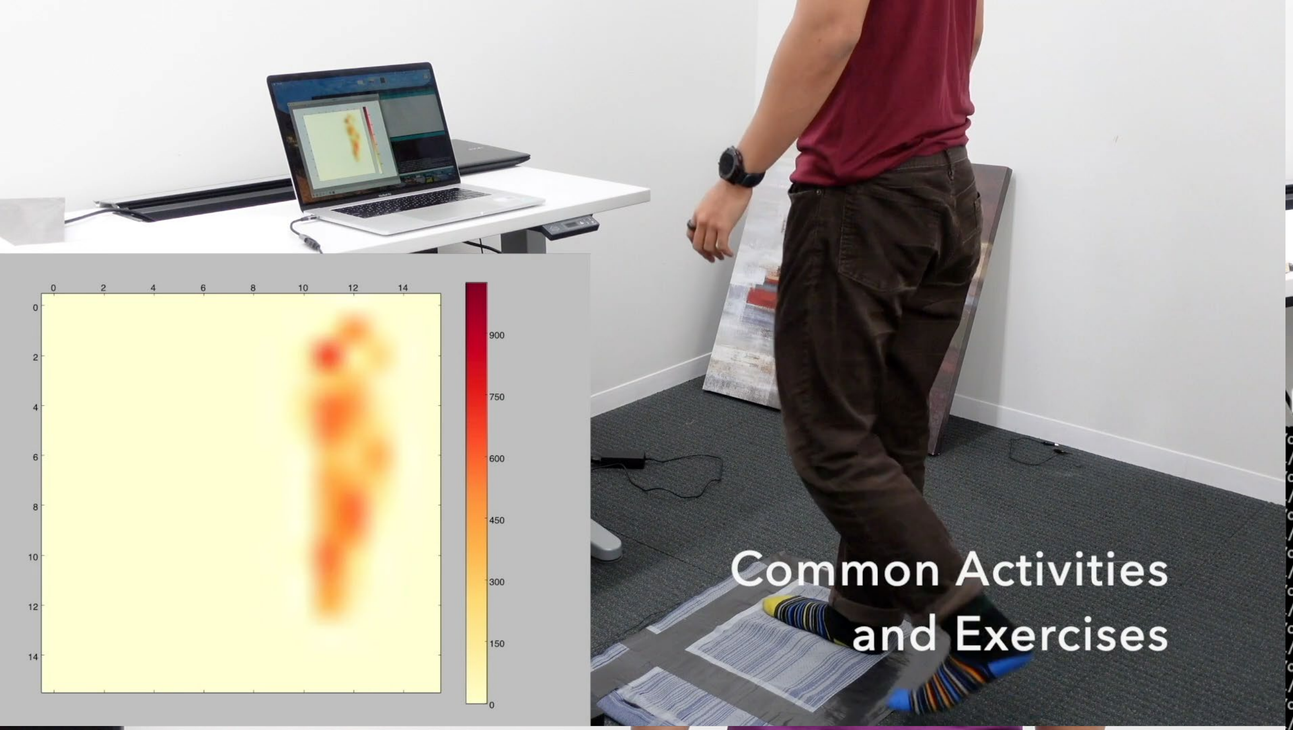
8x10 pressure-sensing pixel (2.5cm pitch)
80 pixels, 24x25 cm

Wicaksono, Hwang, Droubi et al., 3DKnITS, IEEE EMBC (2022)

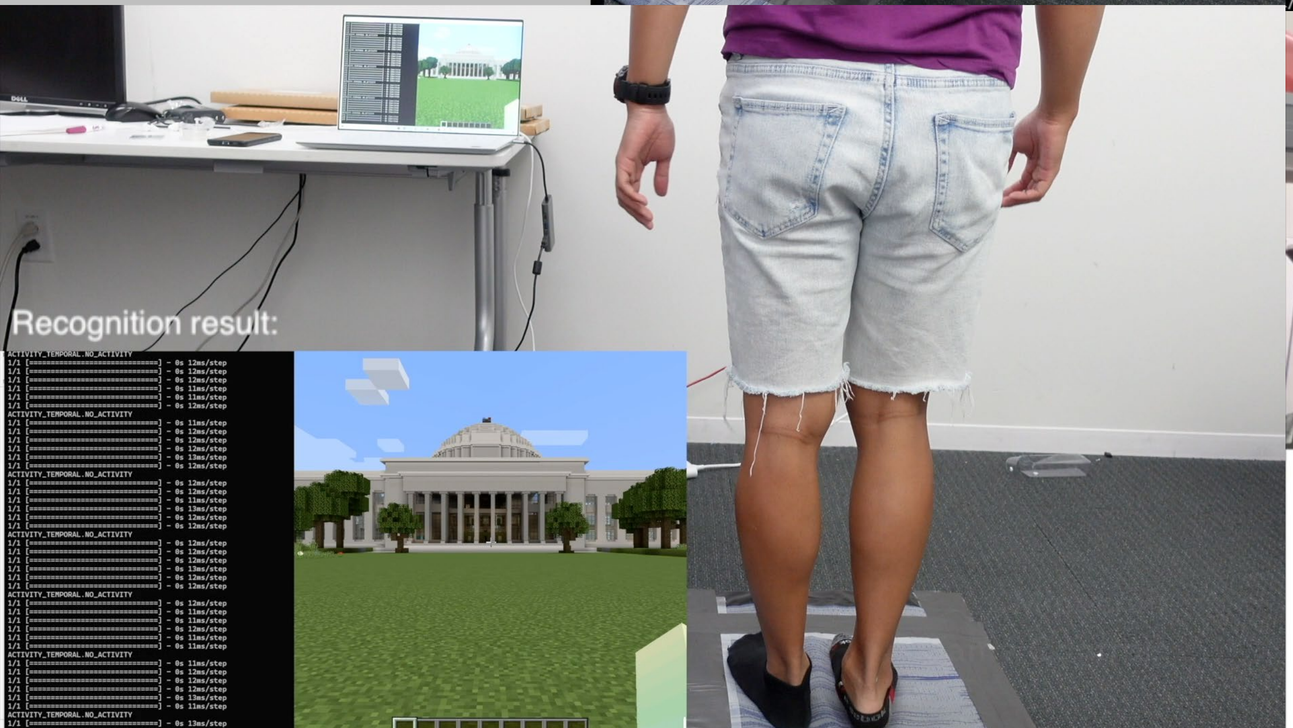
Deep learning-enabled applications

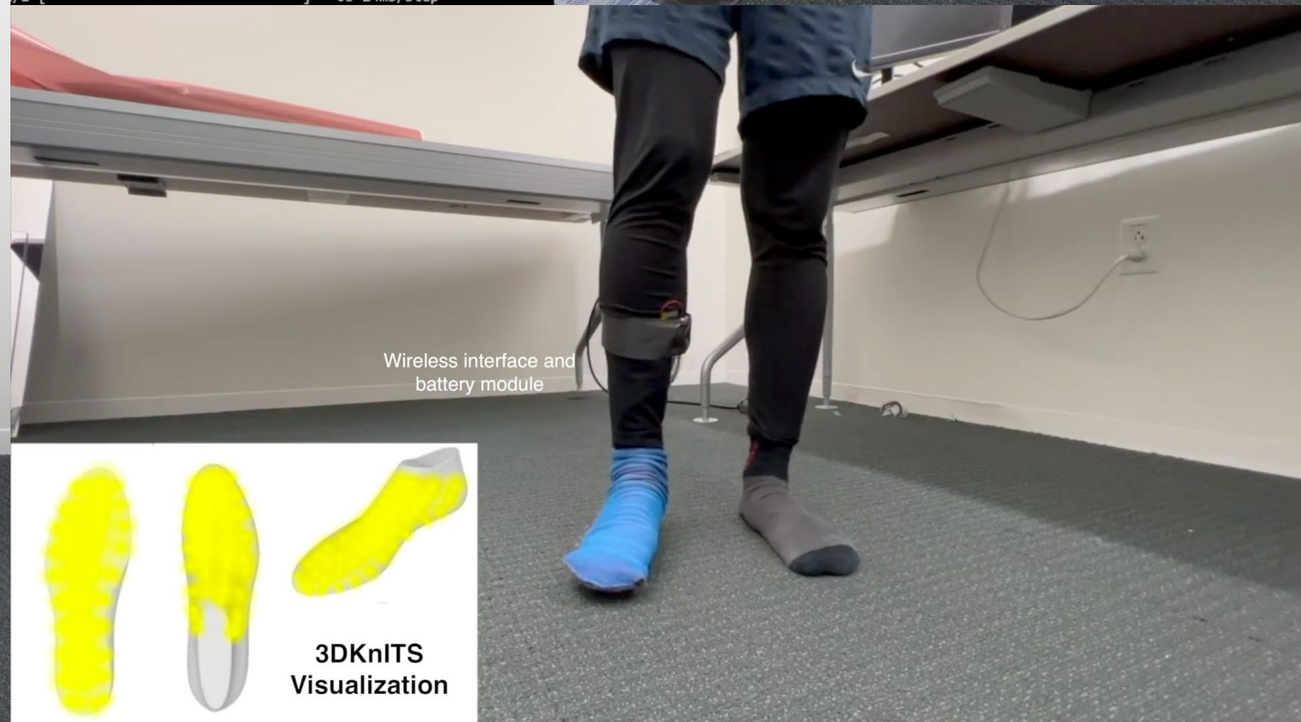


Wicaksono, Hwang, Droubi et al., 3DKnITS, IEEE EMBC (2022)


Common Activities
and Exercises


Recognition result:
oga.TREE
/1 [==============================] - 0s 25ms/step
oga.TREE
/1 [==============================] - 0s 24ms/step
oga.TREE
/1 [==============================] - 0s 23ms/step
oga.TREE
/1 [==============================] - 0s 23ms/step
oga.TREE
/1 [==============================] - 0s 25ms/step
oga.EAGLE_CHALLENGE
/1 [==============================] - 0s 24ms/step
oga.TREE_CHALLENGE
/1 [==============================] - 0s 24ms/step
oga.TREE_CHALLENGE
/1 [==============================] - 0s 24ms/step
Yoga Pose
Recognition


Recognition result:
ACTIVITY_TEMPORAL.NO_ACTIVITY
1/1 [==============================] - 0s 12ms/step

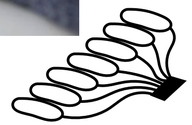

Wireless interface and
battery module
3DKnITS
Visualization

Architecting sensate textiles across scales

Objects

60 touch + 5 stretch + 1 pressure
Capacitive and piezoresistive array
72 connections
0.15m^2 active area

KnittedKeyboard
Musical expression



Body

8 x 12 pressure-sensing sock
Piezoresistive matrix
20 connections
0.072 m^2 active area

16 x 16 pressure-sensing mat
Piezoresistive matrix
32 connections
0.2 m^2 active area

3DKnITS

Activity recognition
Biomechanics

Room-scale

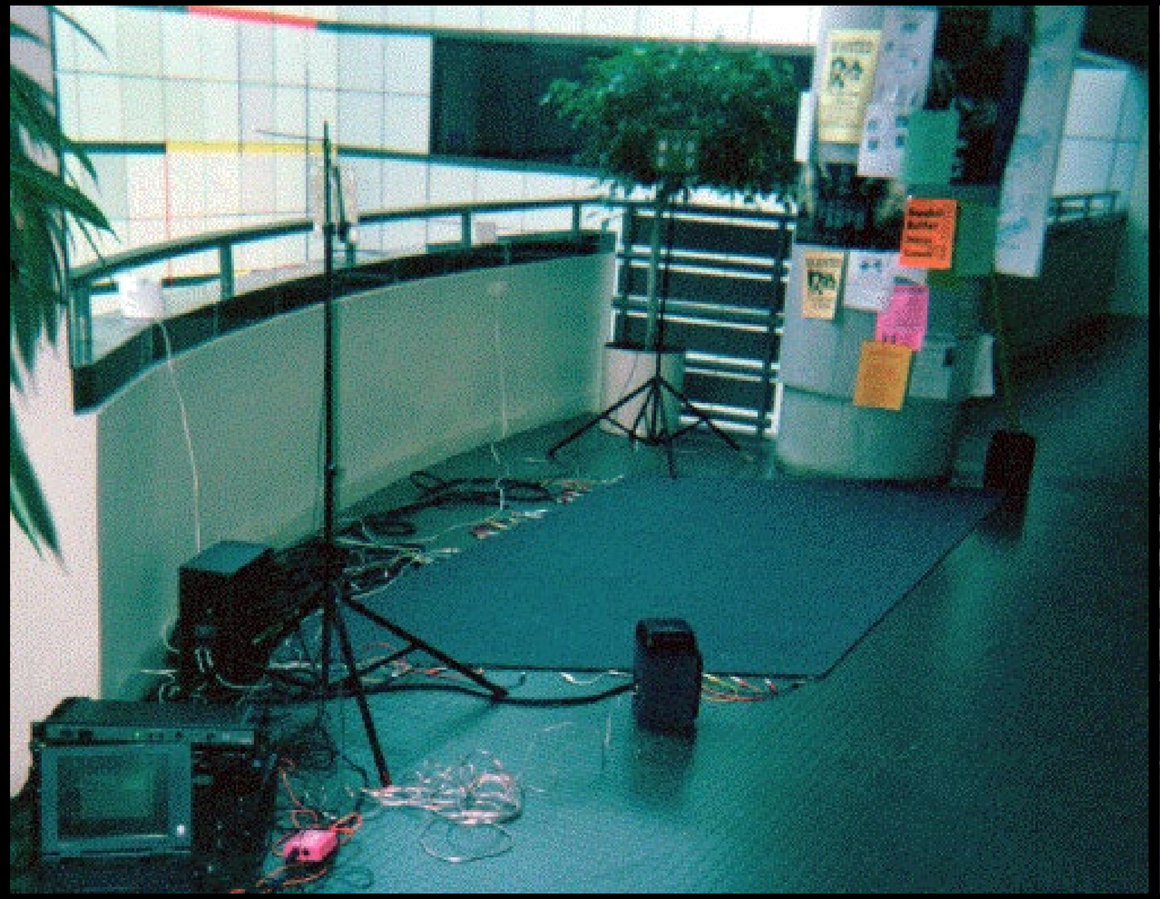
30 x 60 pressure-sensing carpet
Piezoresistive matrix
90 connections
4.5m^2 active area

Tapis Magique

Interactive dance

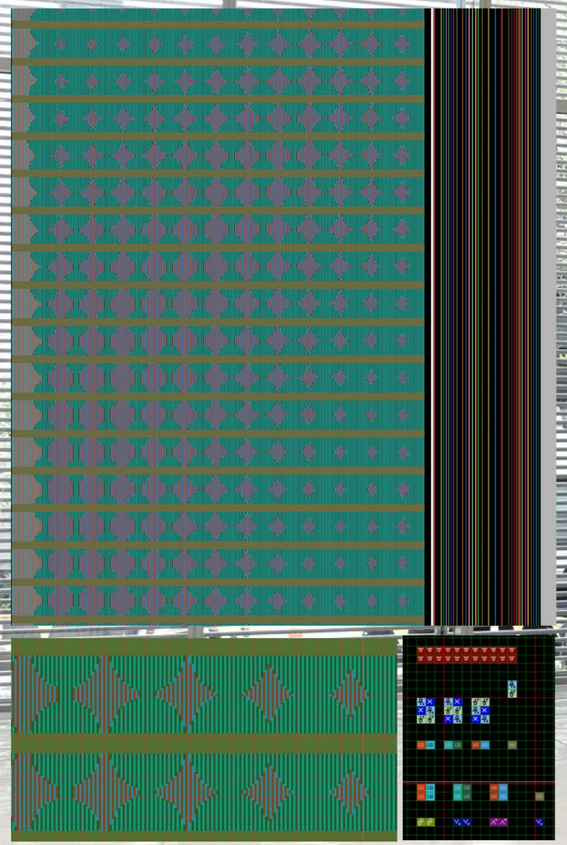
Cage/Cunningham *Variations V*

Related Work



Magic Carpet (1997)
Paradiso, Hsiao, Greenworld

Tapis Magique



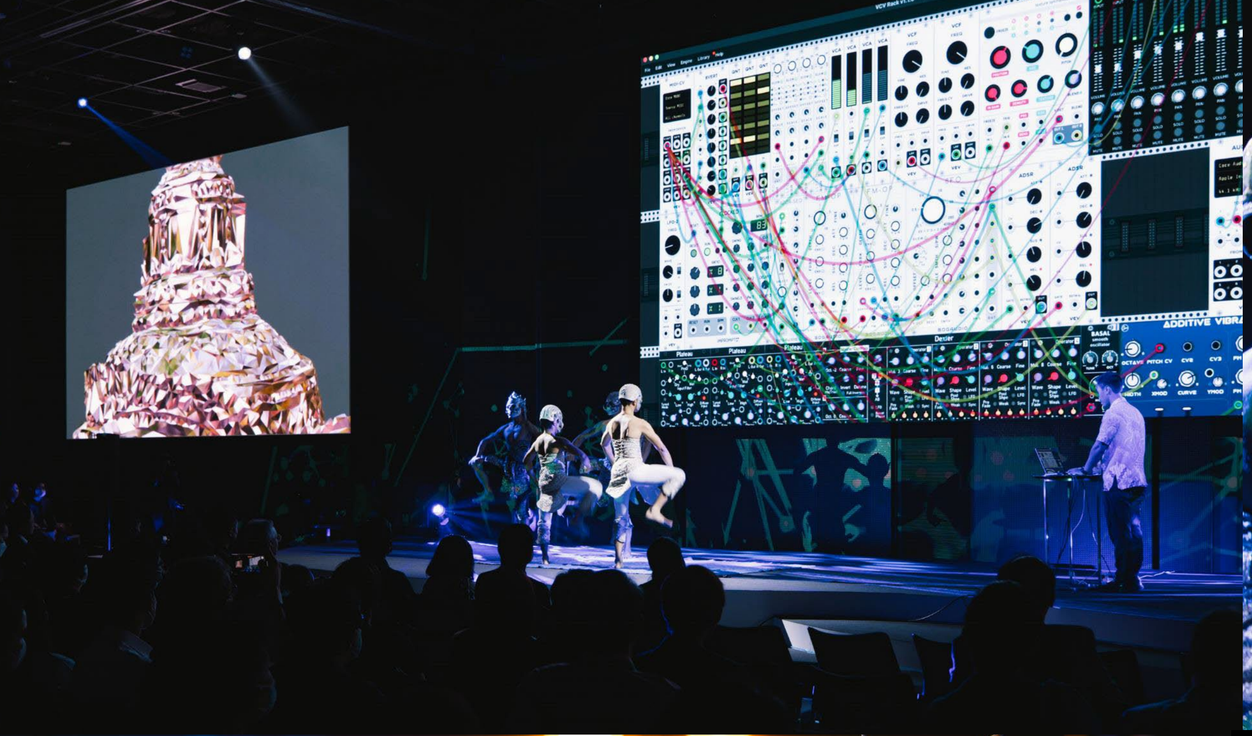
Wicaksono, Haddad, and Paradiso, Tapis Magique, ACM C&C(2022)

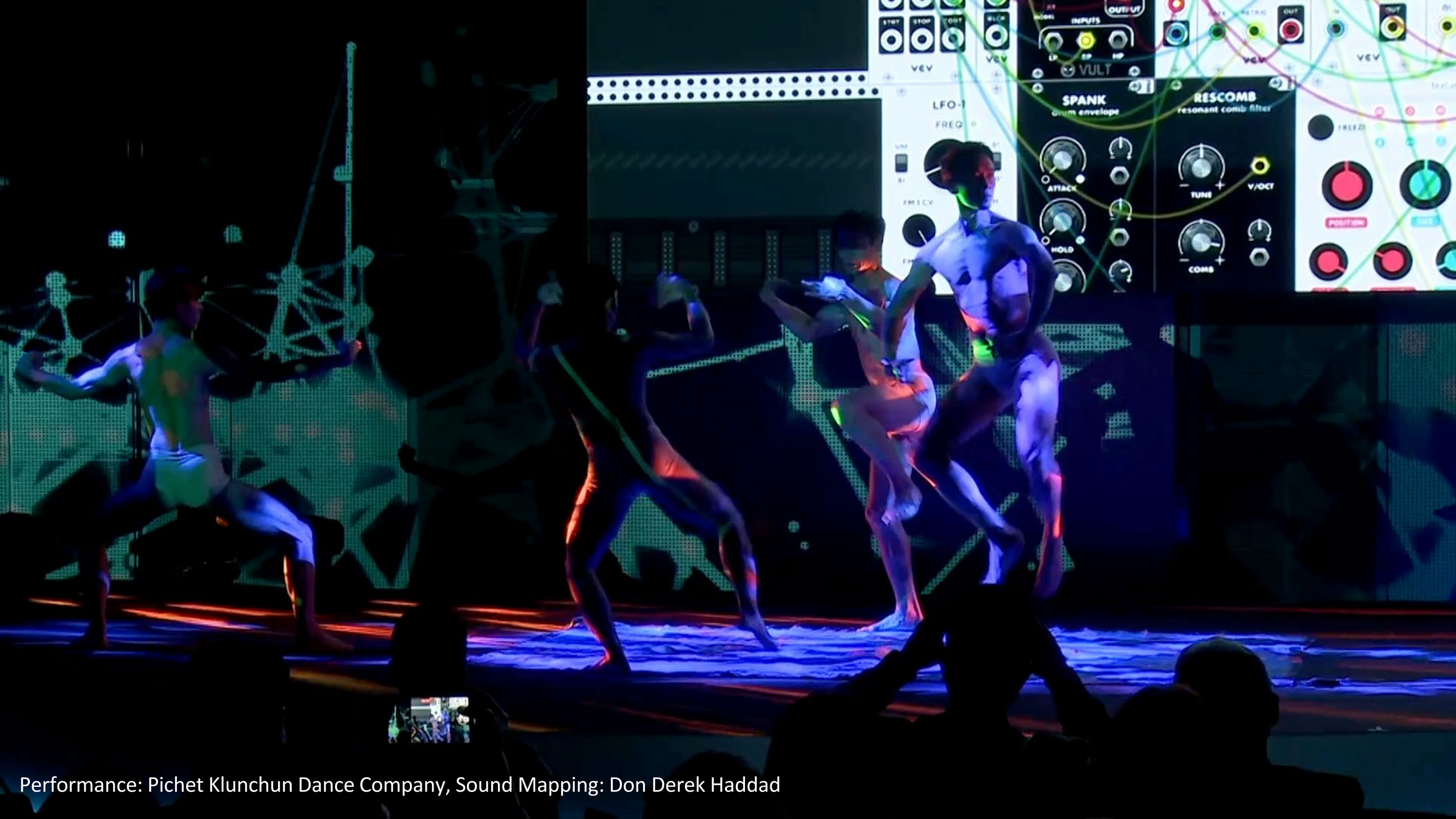
Wicaksono, Haddad, and Paradiso, Tapis Magique, ACM C&C(2022)

Choreographer, Dancer: Loni Landon, Sound Mapping: Don Derek Haddad

Choreographer, Dancer: Loni Landon, Sound Mapping: Don Derek Haddad

Choreographer, Dancer: Loni Landon, Sound Mapping: Don Derek Haddad





Performance: Pichet Klunchun Dance Company, Sound Mapping: Don Derek Haddad

Architecting sensate textiles across scales

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3DKnITS

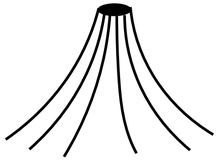
Activity recognition
Biomechanics

Building

24 Tx/Rx antennas
Active capacitive/e-field
24 connections
25m^2 active area

Tapis Magique

Interactive dance



Living Knitwork Pavilion

Immersive environments
Telepresence

Black Rock City, NV

Courtesy of Vincent Rommelaere

Living Knitwork Pavilion

Related Work

Lumen (2017)
Jenny Sabin Studio
MoMA PS1, New York

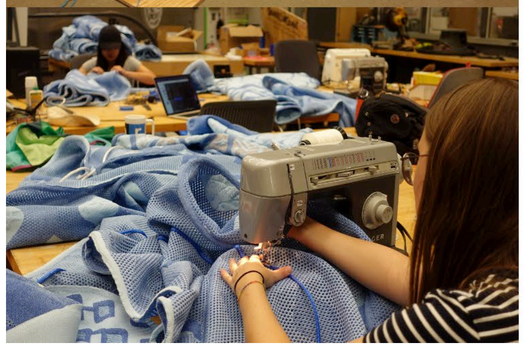
KnitCandela (2018)
Block Research Group/ETH Zurich & Zaha Hadid Architects
MUAC, Mexico City

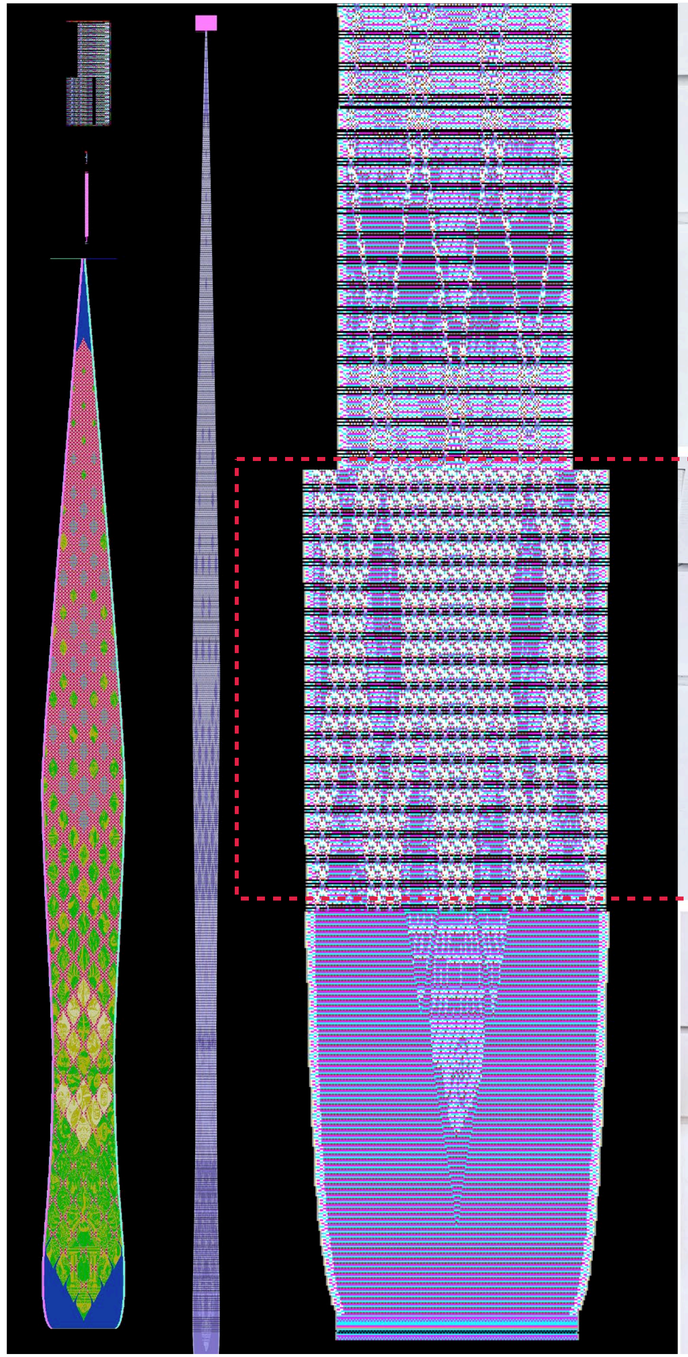
Living Knitwork Pavilion

Living Knitwork Pavilion

Textile popped-up paterns, inspired by cultural heritage

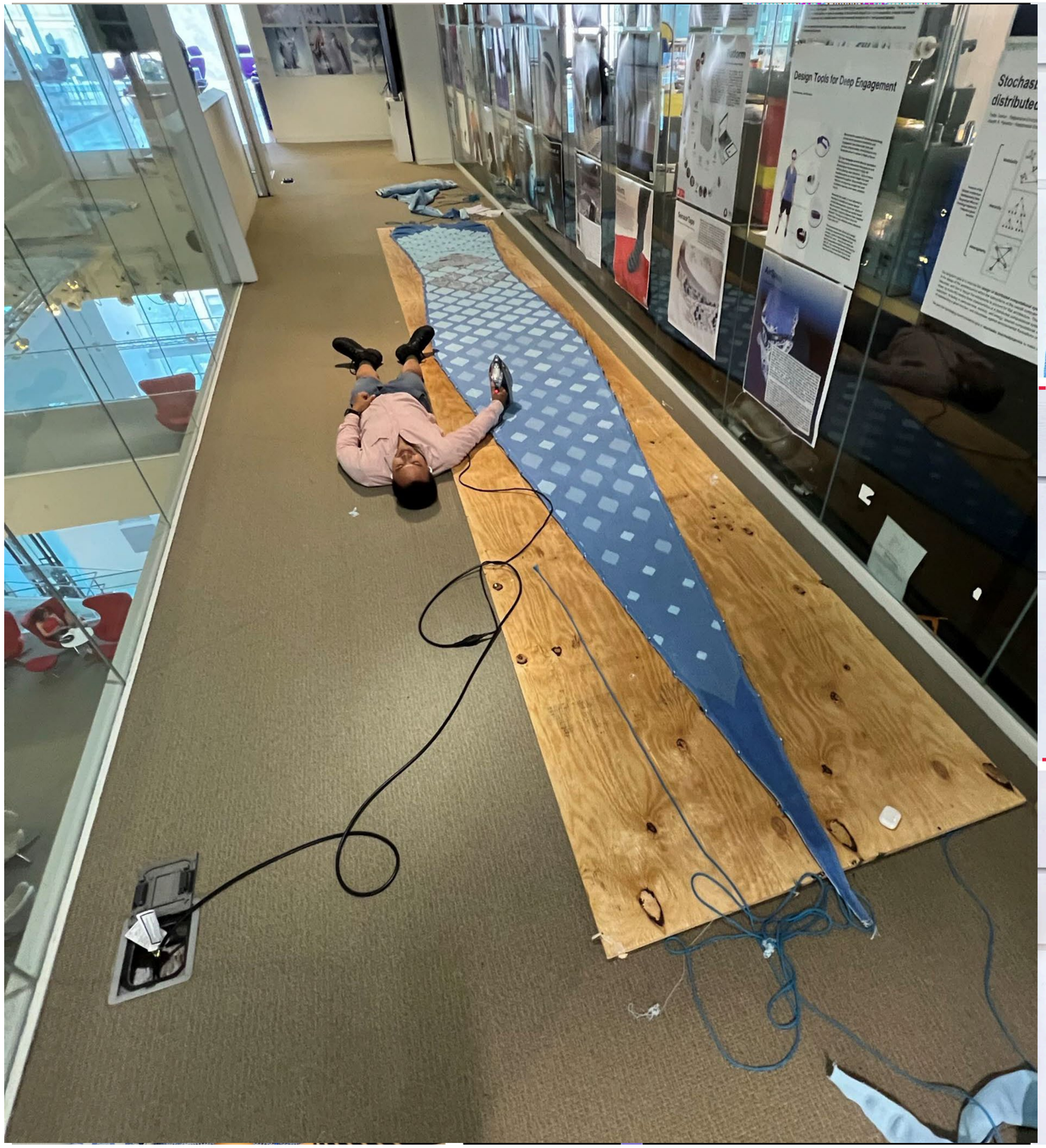
Balinese Pura





Digital Knitting of Sensate Textiles

Wicaksono, Rubio, Cichoka et al., Living Knitwork Pavilion, *paper in review* (2024)

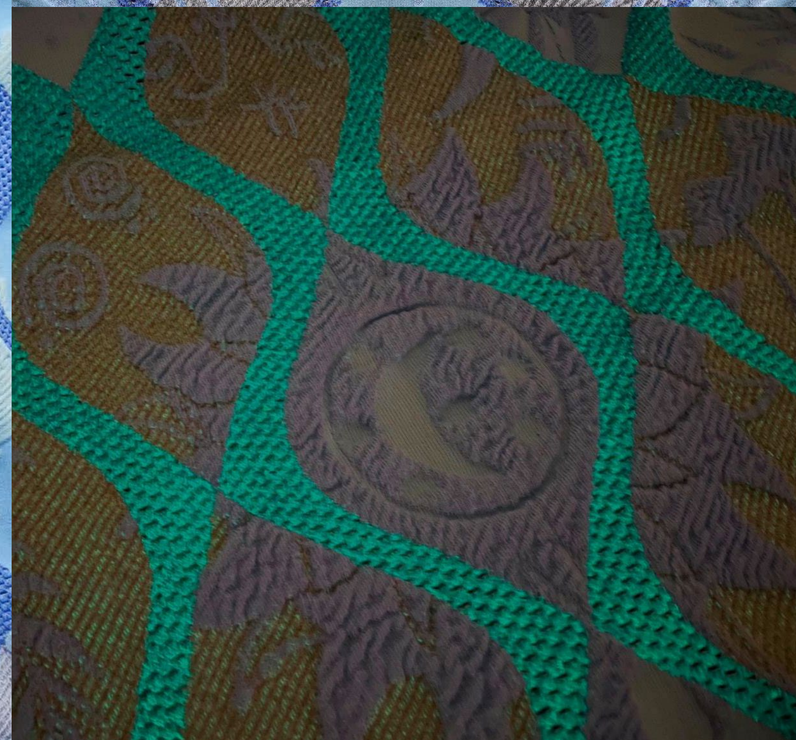


Digital Knitting of Sensate Textiles

Wicaksono, Rubio, Cichoka et al., Living Knitwork Pavilion, *paper in review* (2024)

Living Knitwork Pavilion

Integrated functional yarns



=Digital Knitting of Sensate Textiles

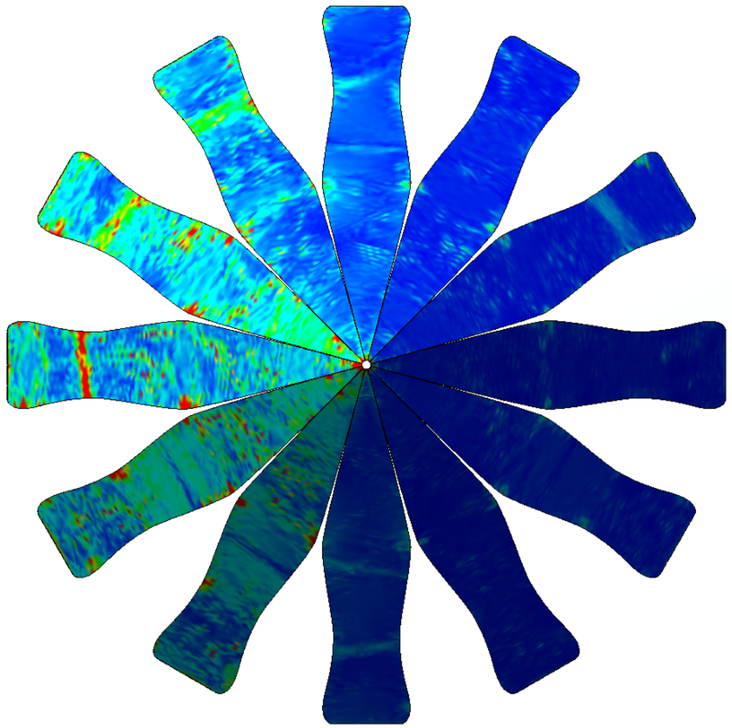
Living Knitwork Pavilion

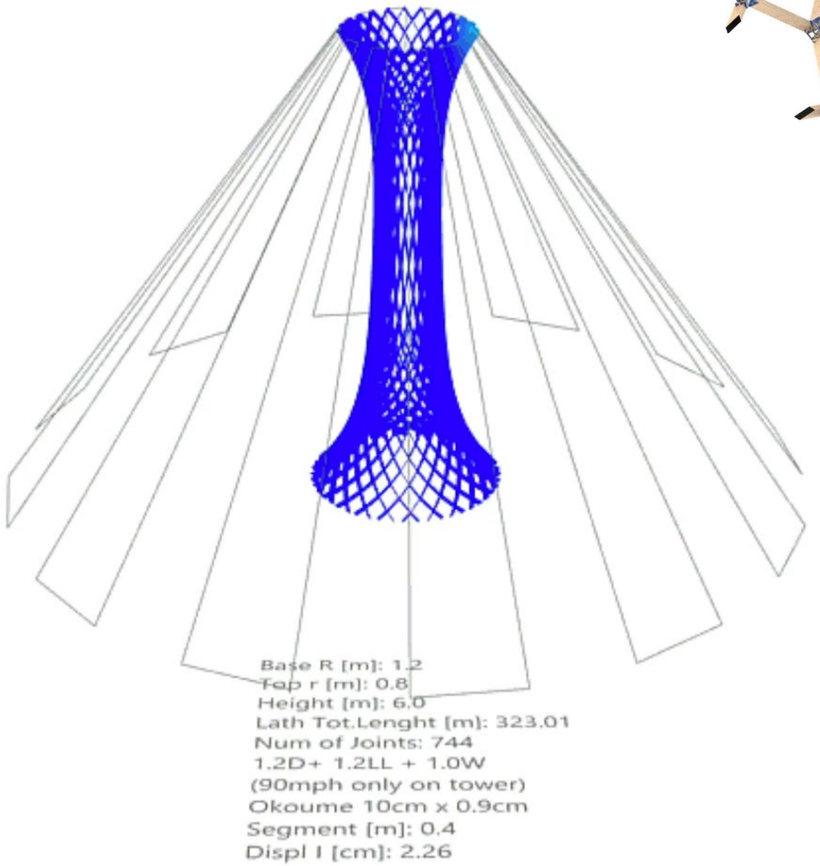
On-site building crew

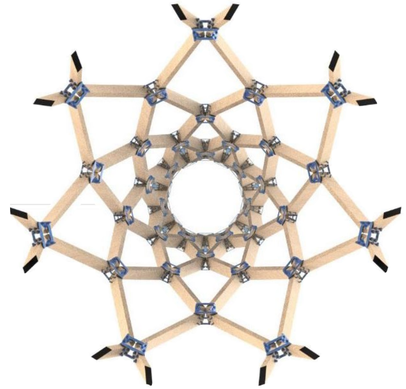
Age van der Mei
Sam Chin,
Judyta Cichoka
Gabriela Advincula
Erik Strand
Alfonso Parra Rubio,
Nicole Bakker

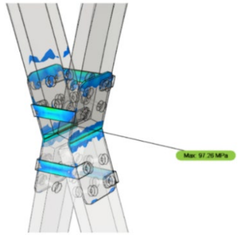
Living Knitwork Pavilion

Designing temporary structures for extreme environments









Wind simulation: Tongge Yu
Central structure design: Judyta Cichoka, Alfonso Parra Rubio

Wicaksono, Rubio, Cichoka et al., Living Knitwork Pavilion, *accepted* (2024)

Timelapse: Gabriela Advincula

Timelapse: Gabriela Advincula

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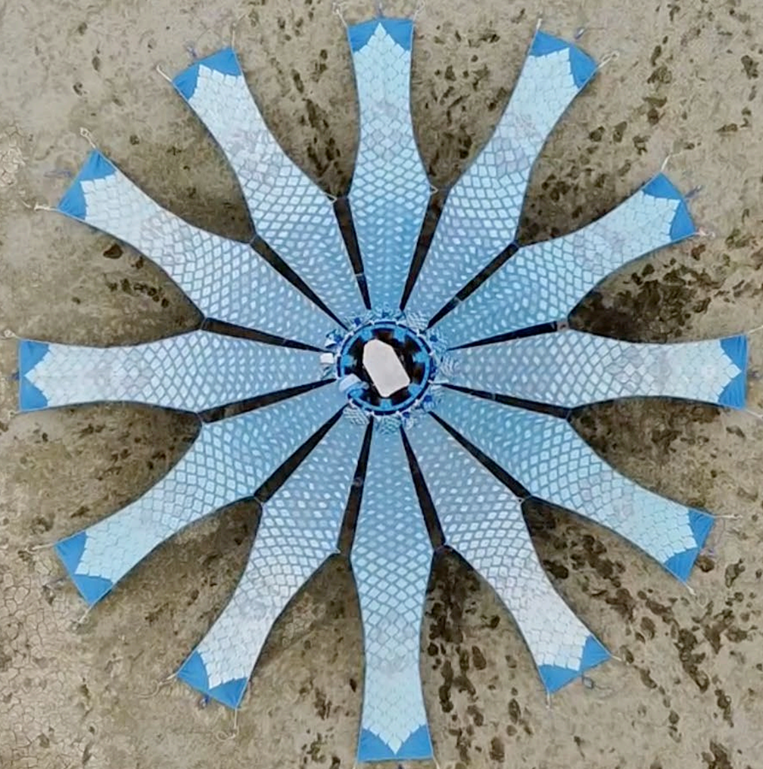
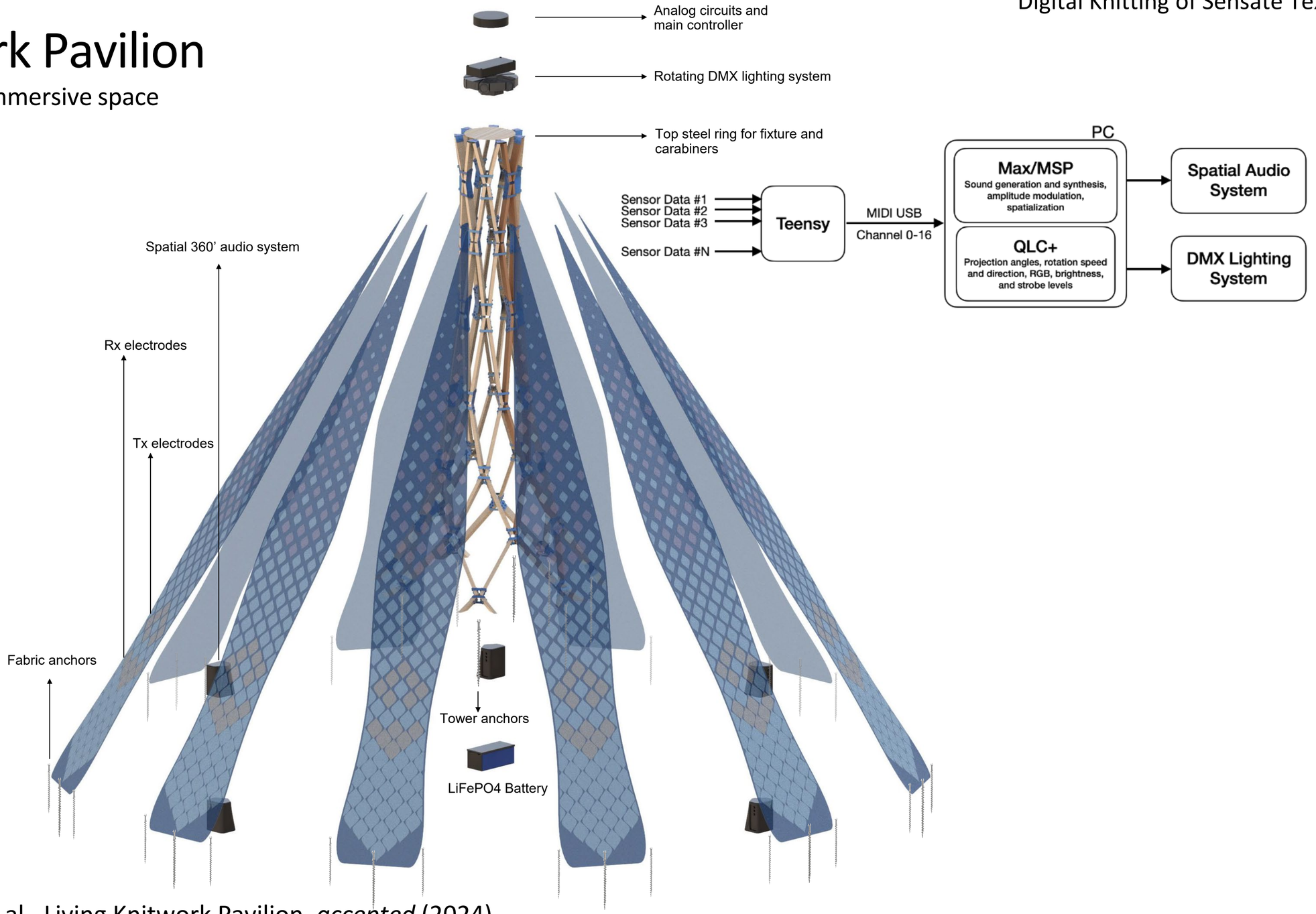


Living Knitwork Pavilion

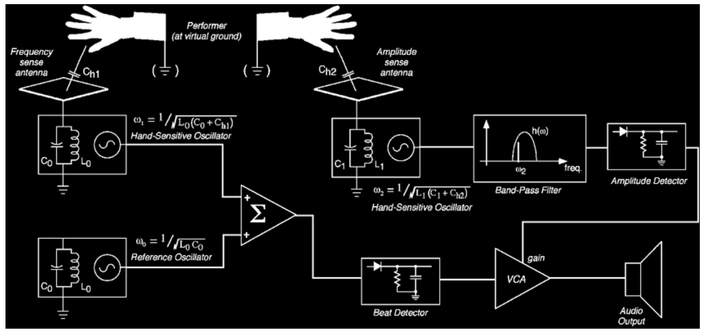
Integrated system for an immersive space

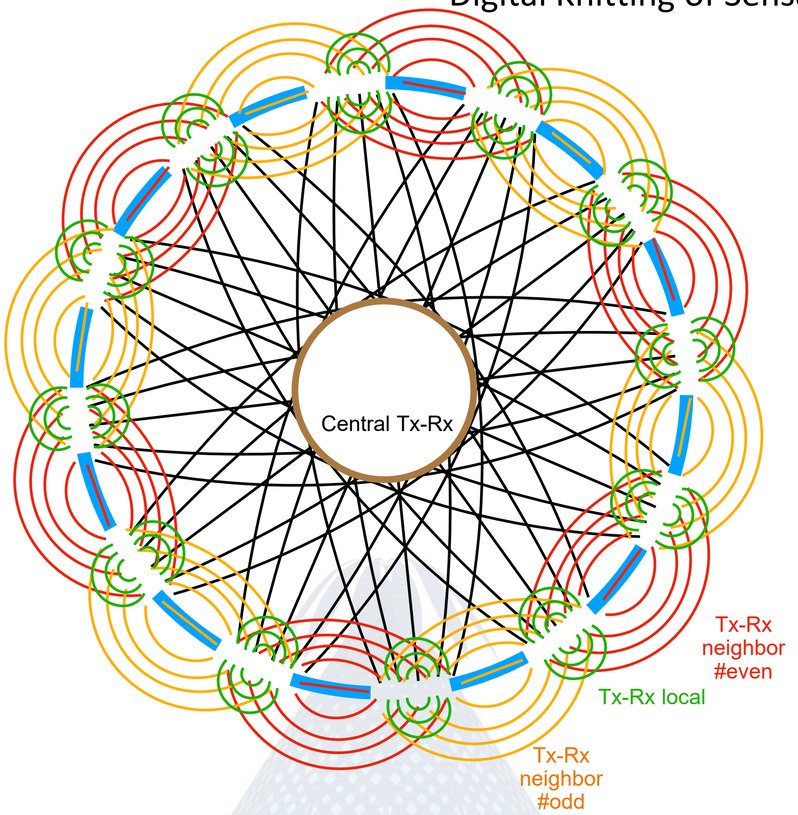


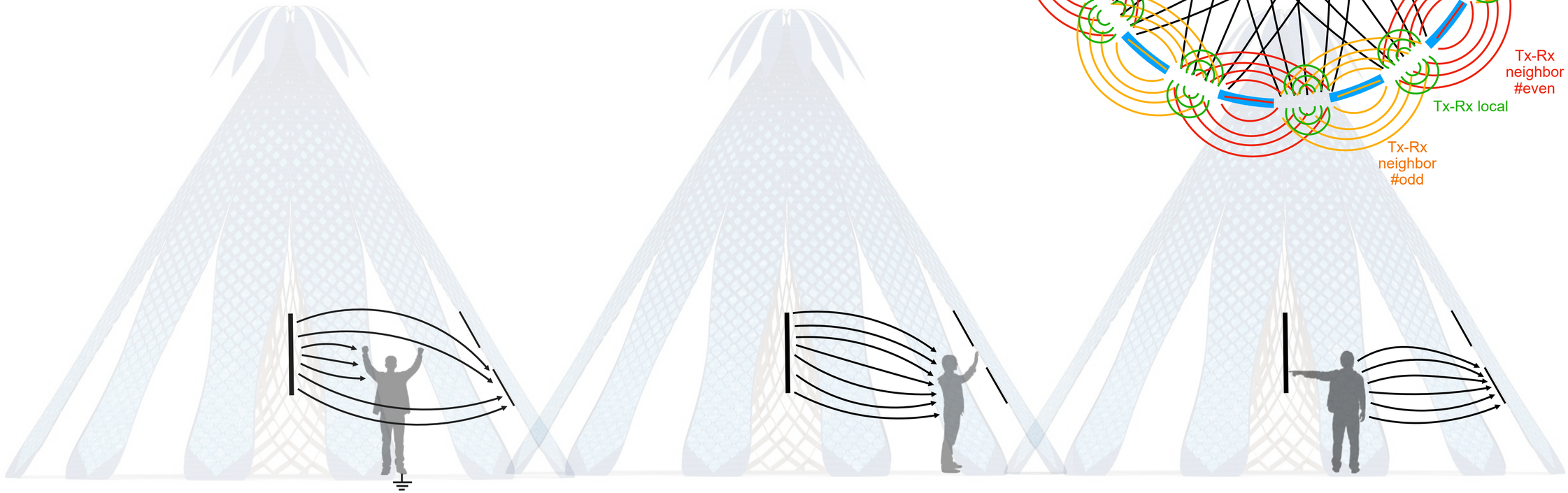
Wicaksono, Rubio, Cichoka et al., Living Knitwork Pavilion, *accepted* (2024)

Living Knitwork Pavilion

An architectural theremin, distributed e-field sensing





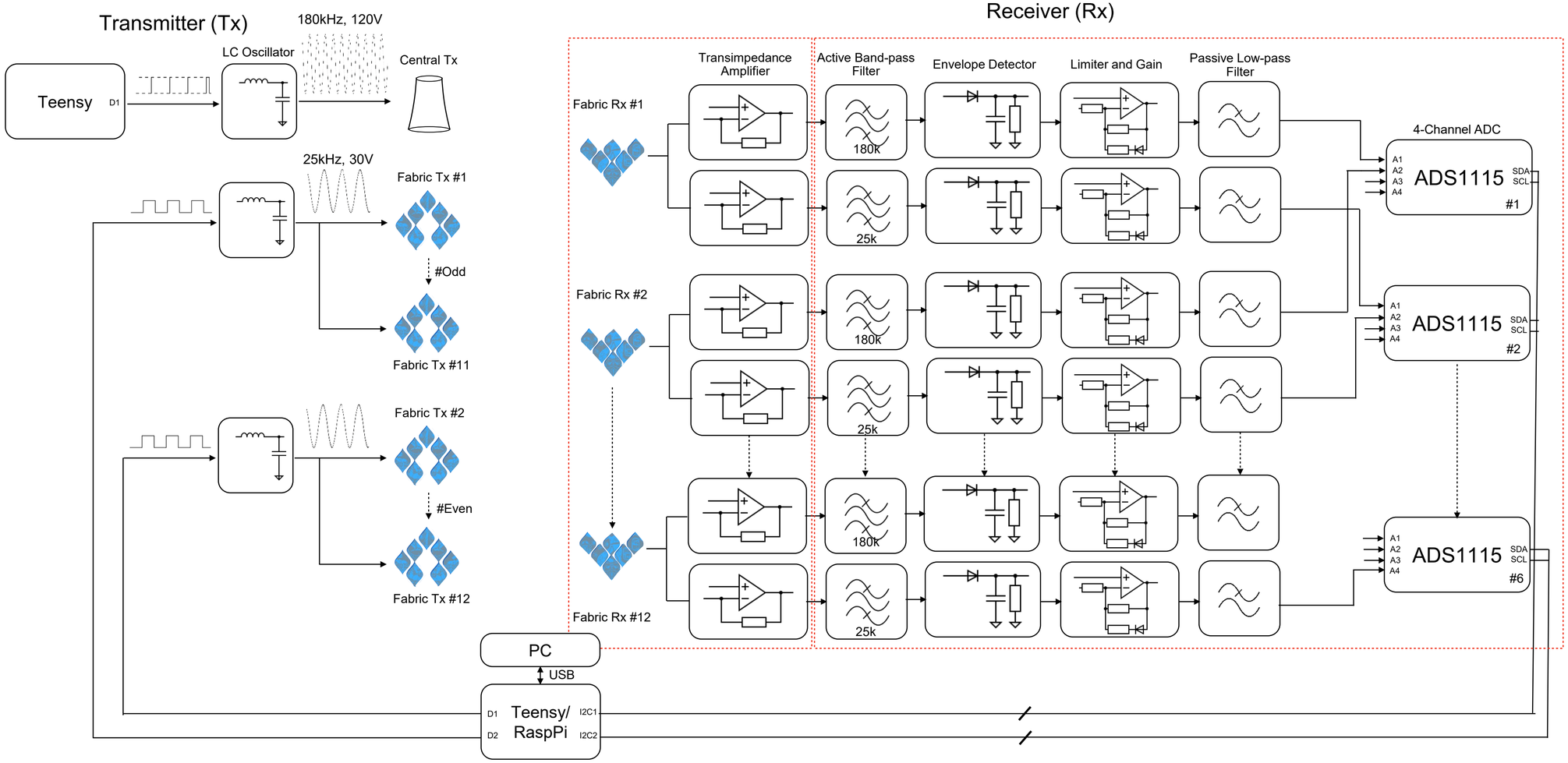


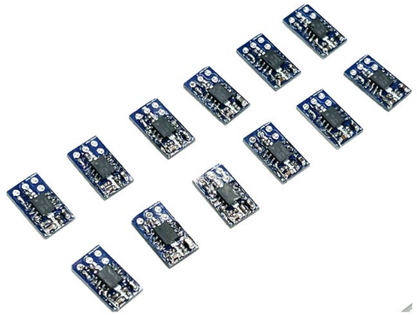
Shunt Mode | Receive Mode | Transmit Mode

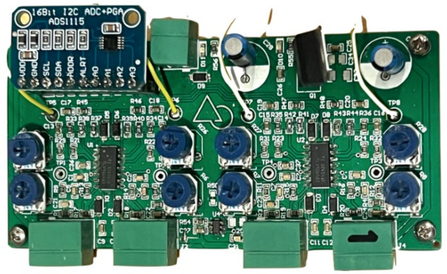
Wicaksono, Rubio, Cichoka et al., Living Knitwork Pavilion, *accepted* (2024)

Living Knitwork Pavilion

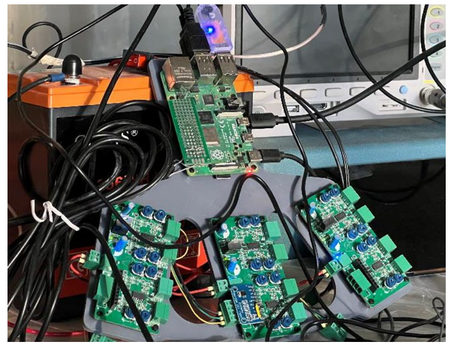
Hardware system for e-field sensing







Transimpedance and Rx circuit

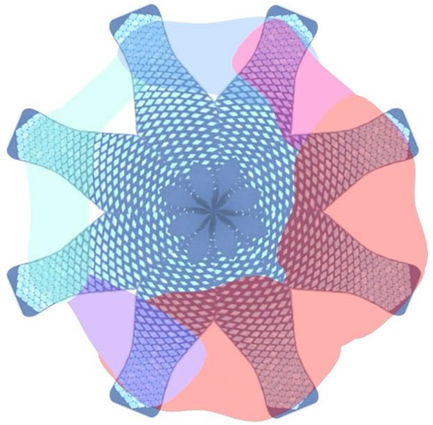


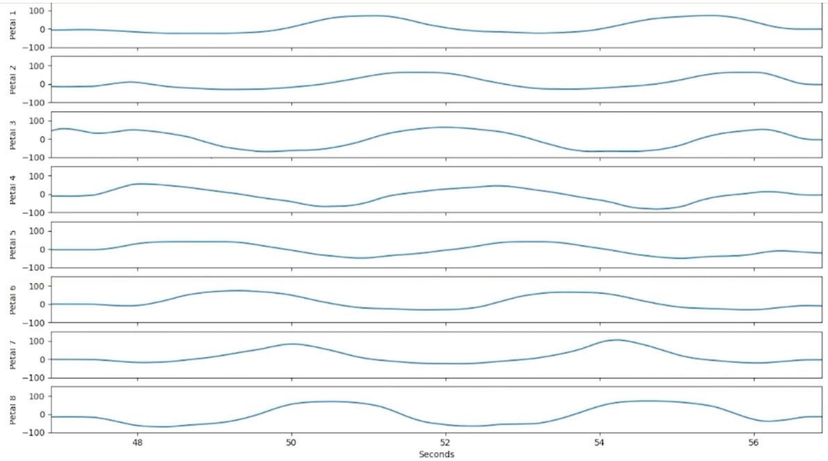
Central module

Hardware design with Sam Chin

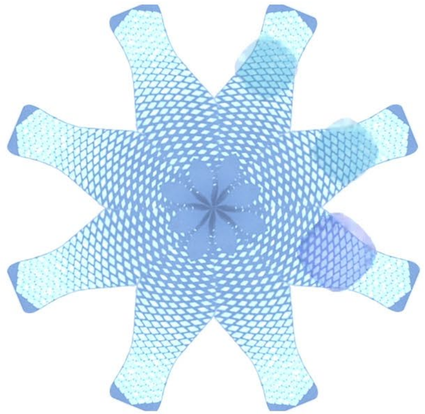
Wicaksono, Rubio, Cichoka et al., Living Knitwork Pavilion, *accepted* (2024)

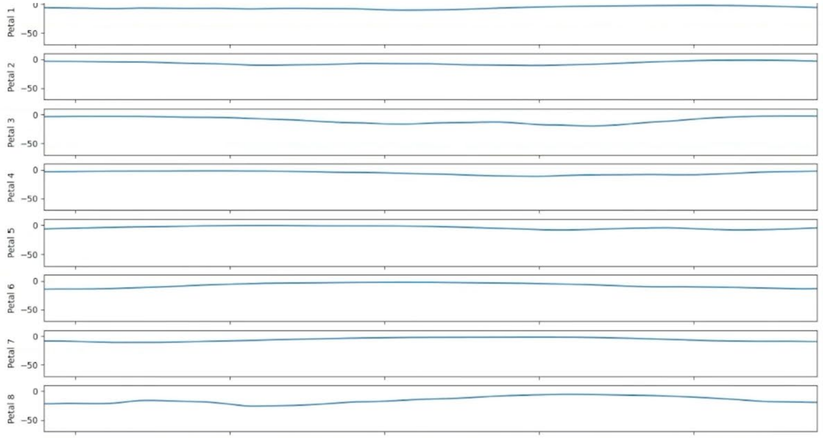
Transmit mode



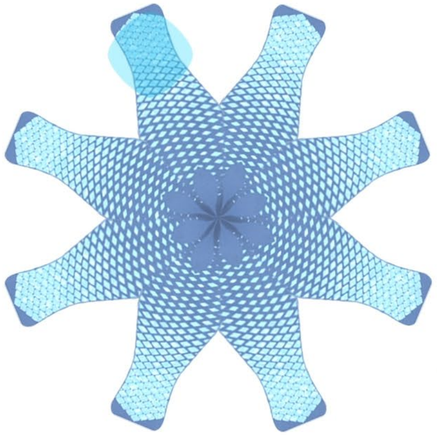


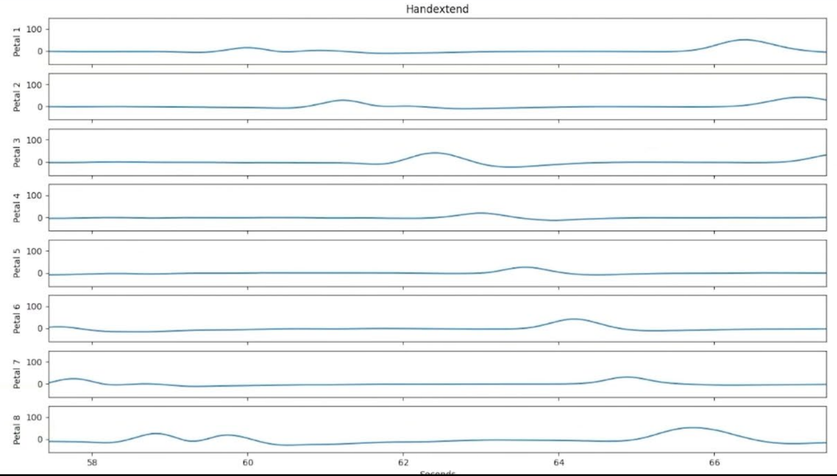
Shunt mode





Receive mode





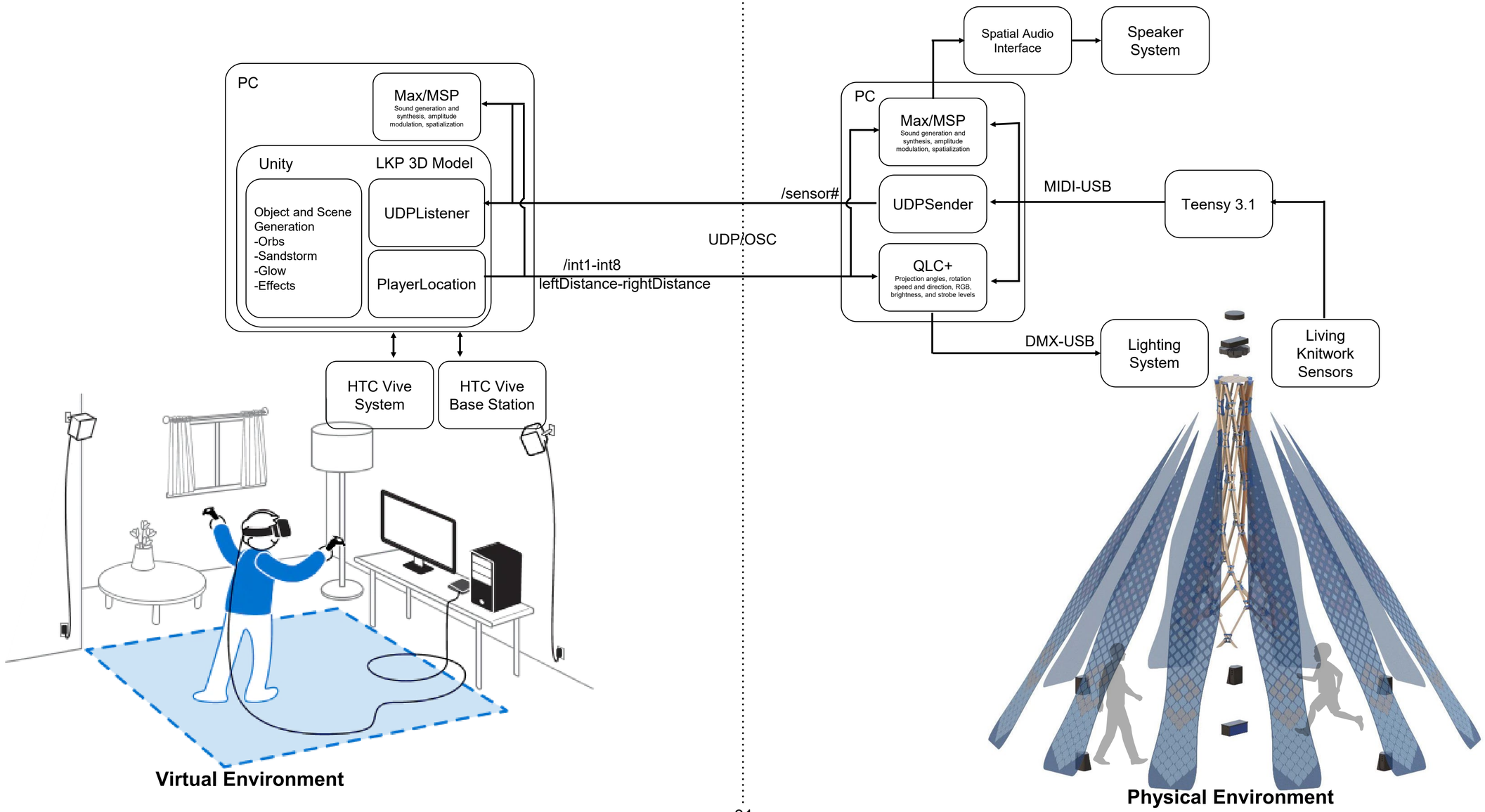
Video: Manaswi Mishra

Choreographer: Treyden Chiavaralotti, Sound Mapping: Don Derek Haddad

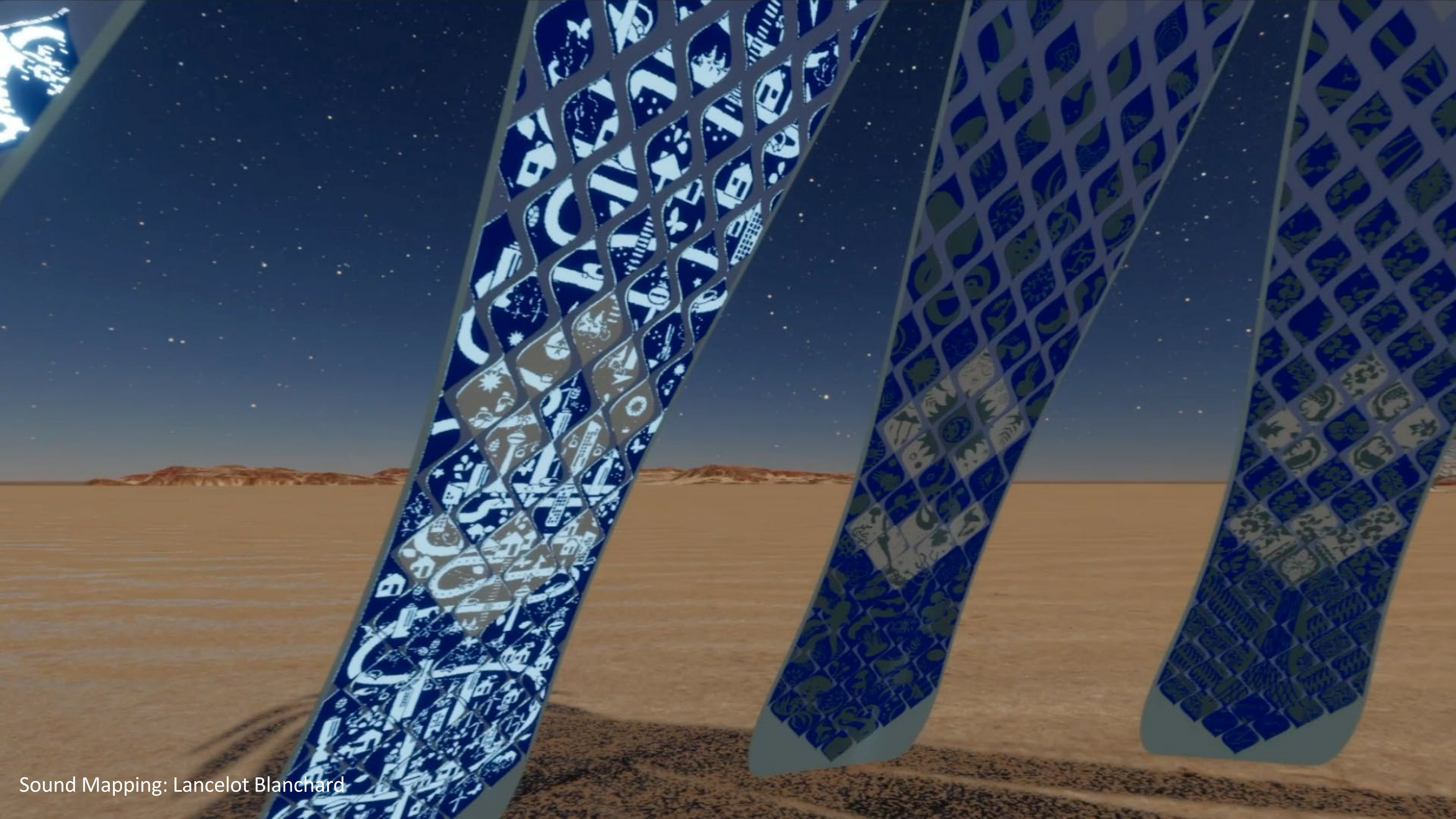
Choreographer: Treyden Chiavaralotti, Sound Mapping: Don Derek Haddad

KnitworkVR: A dual-reality telepresence experience

Connecting to the virtual and *vice versa*, driven by real-time sensor data and interaction



Wicaksono, Colon, Chin et al., KnitworkVR, *paper in review* (2024)

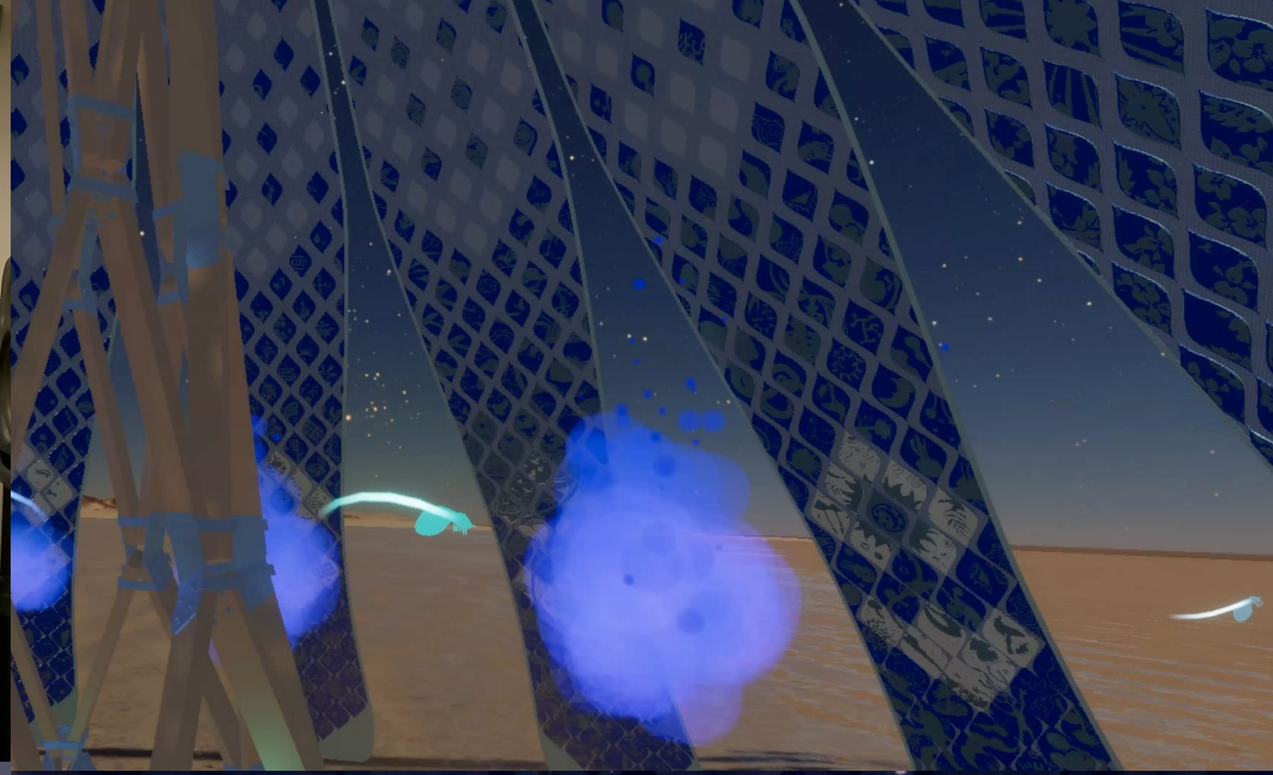

Sound Mapping: Lancelot Blanchard

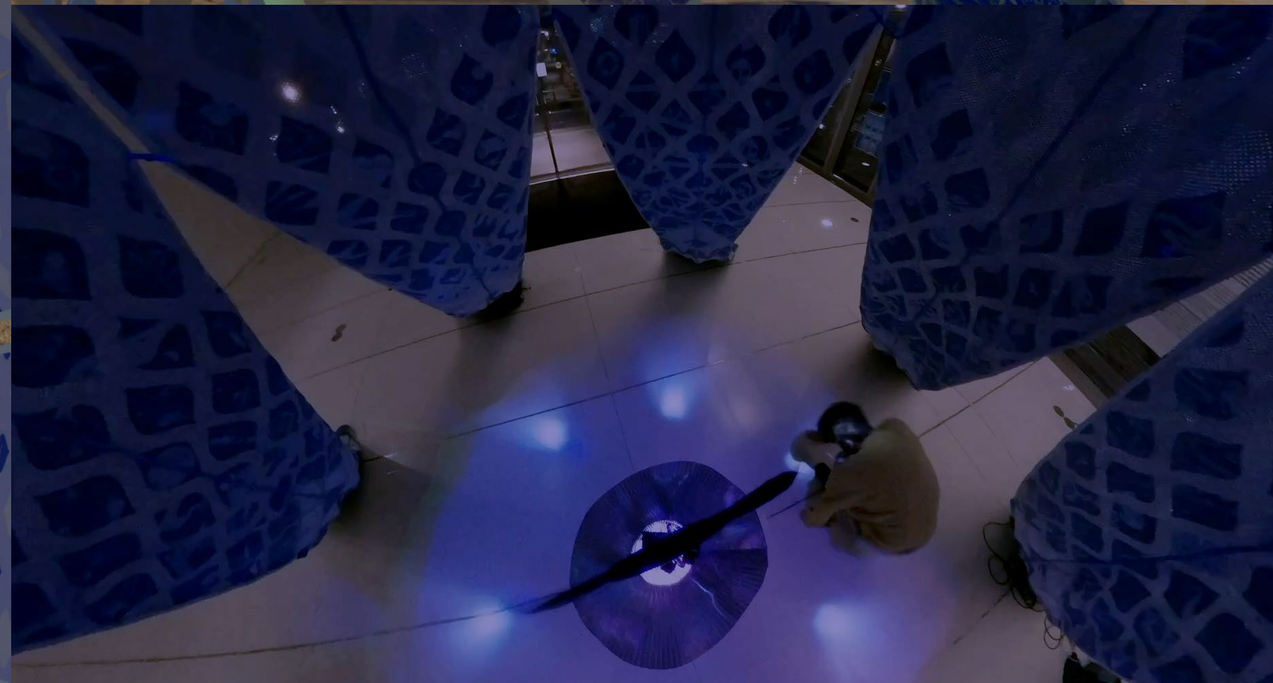

EXIT
CAUTION
LIVING
KNITWORK
PAVILION

Sound Mapping: Lancelot Blanchard


Sound Mapping: Lancelot Blanchard

KnitworkVR





Architecting sensate textiles across scales

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0.15m^2 active area

KnittedKeyboard
Musical expression

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3DKnITS

Activity recognition
Biomechanics

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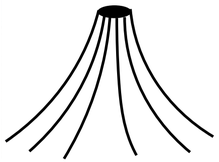
Active capacitive/e-field
24 connections
25m^2 active area

Tapis Magique

Interactive dance



Living Knitwork Pavilion

Immersive environments
Telepresence

Architecting sensate textiles across scales

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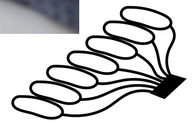

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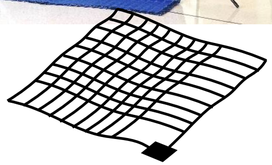

3DKnITS

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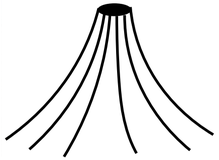


Living Knitwork Pavilion

Immersive environments
Telepresence

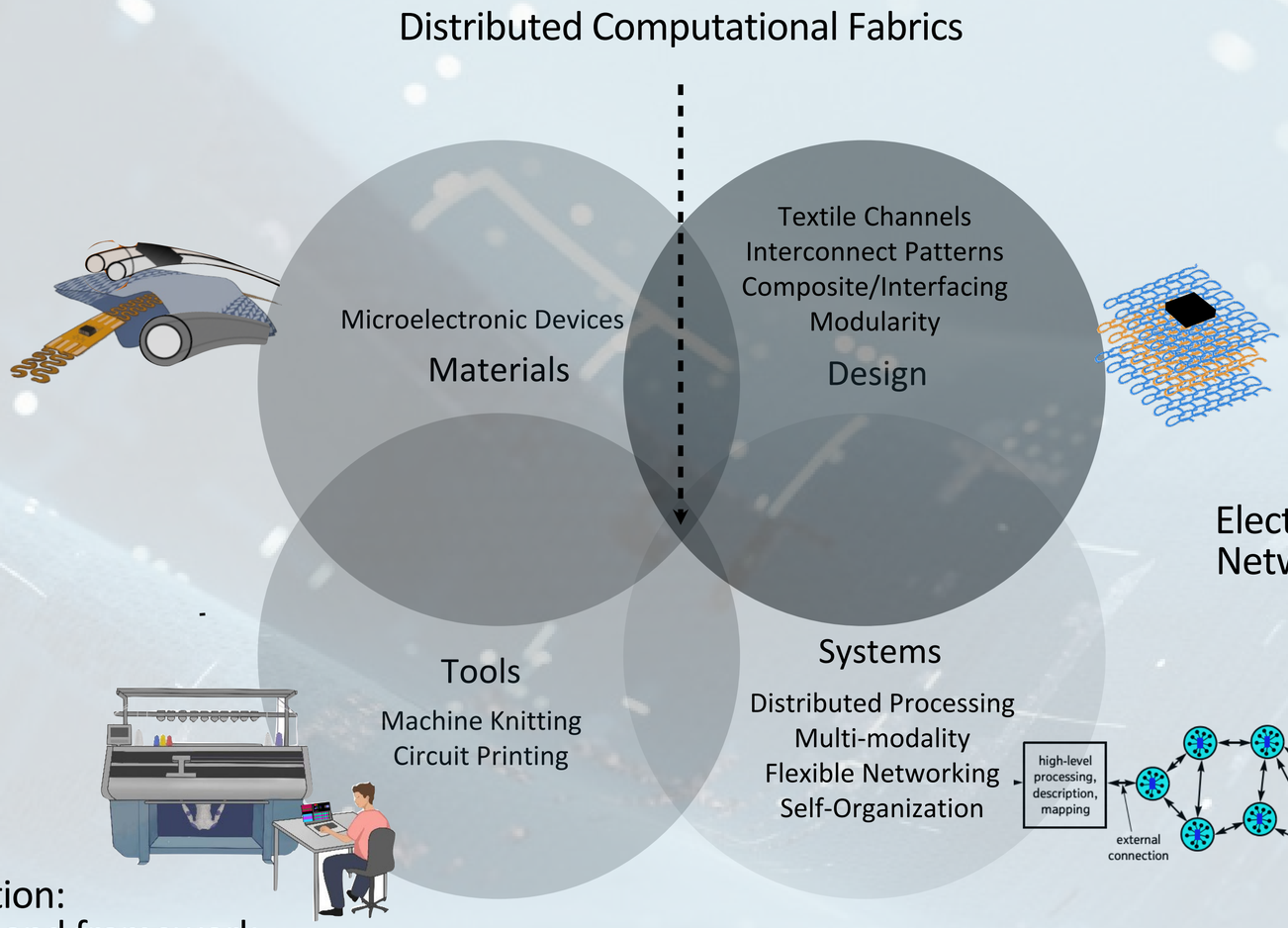
Tapis Magique

Interactive dance

Common challenges:

- Wiring implementation is complex
- Node is not scalable
- Frequency reduction as *n* increases
- Fault/damage-sensitive
- Application-specific

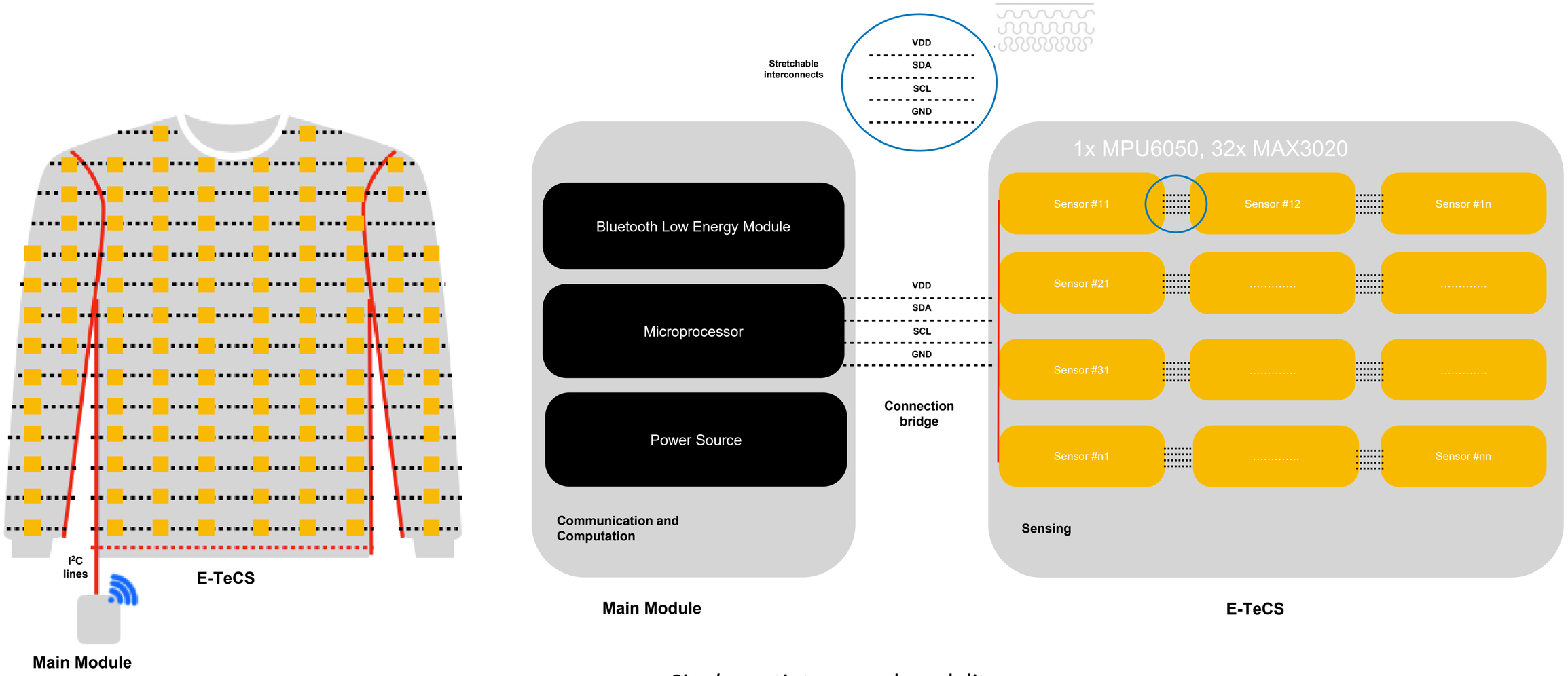
Computational Fabrics Framework



Projects:
Electronic Textile Conformable Suit (E-TeCS)
Networked Electronic Textile System (NETS)

Contribution:
Design methodology and framework
Project artifact across scales
Hardware system development
Application space

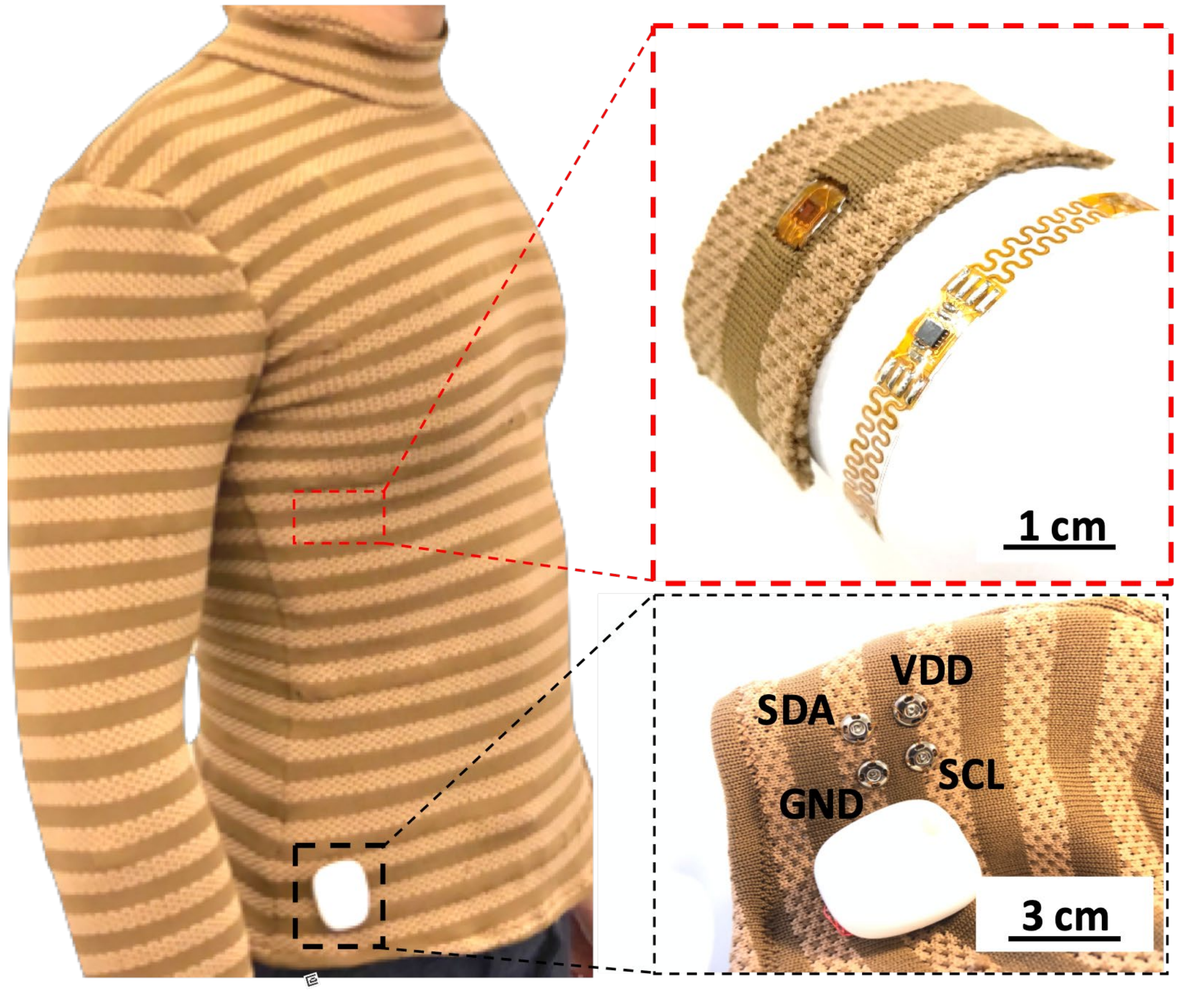
E-TeCS: System Architecture

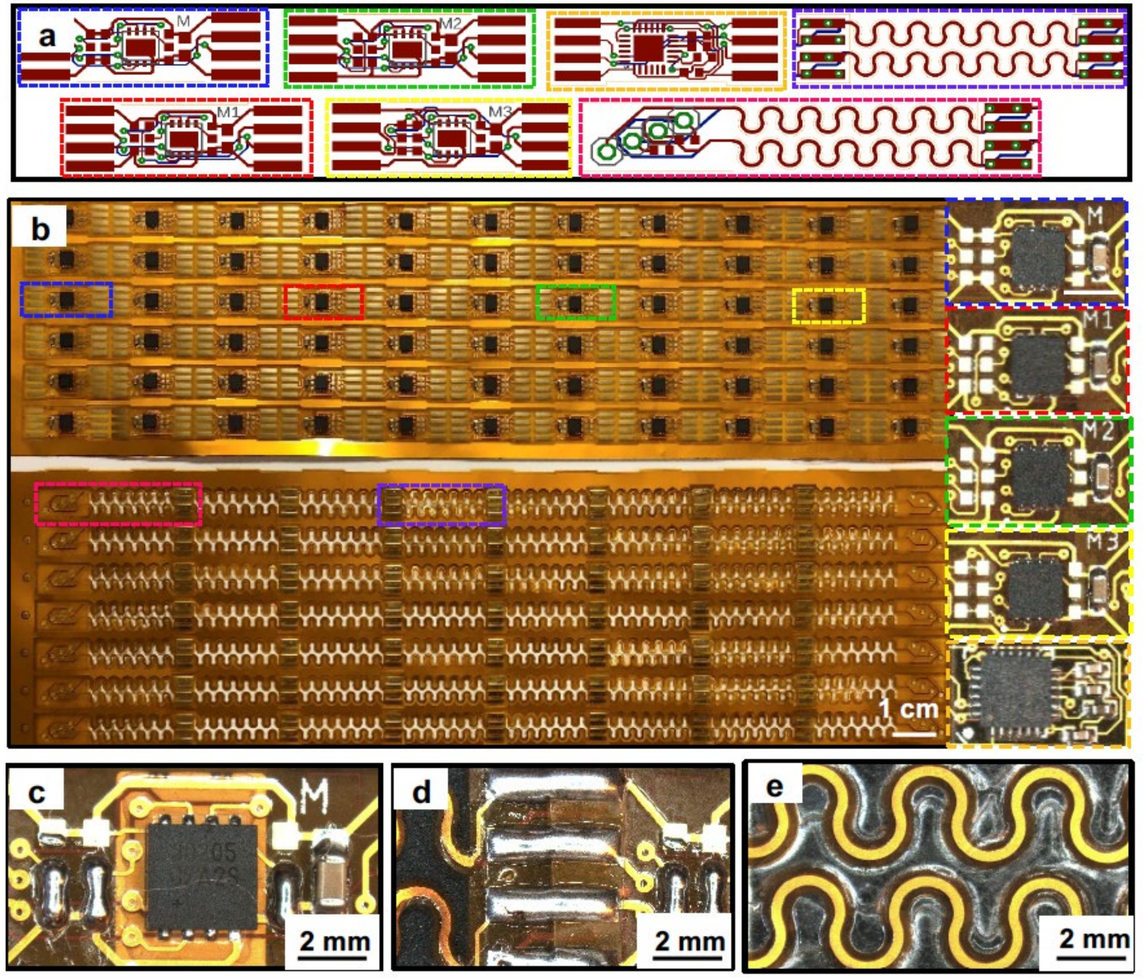


Single spatiotemporal modality:
I2C Temperature Sensor is hard-wired to a maximum of *32 addresses*

Wicaksono, Tucker, Sun et al., E-TeCS, *in Nature Flex. El.* (2020)

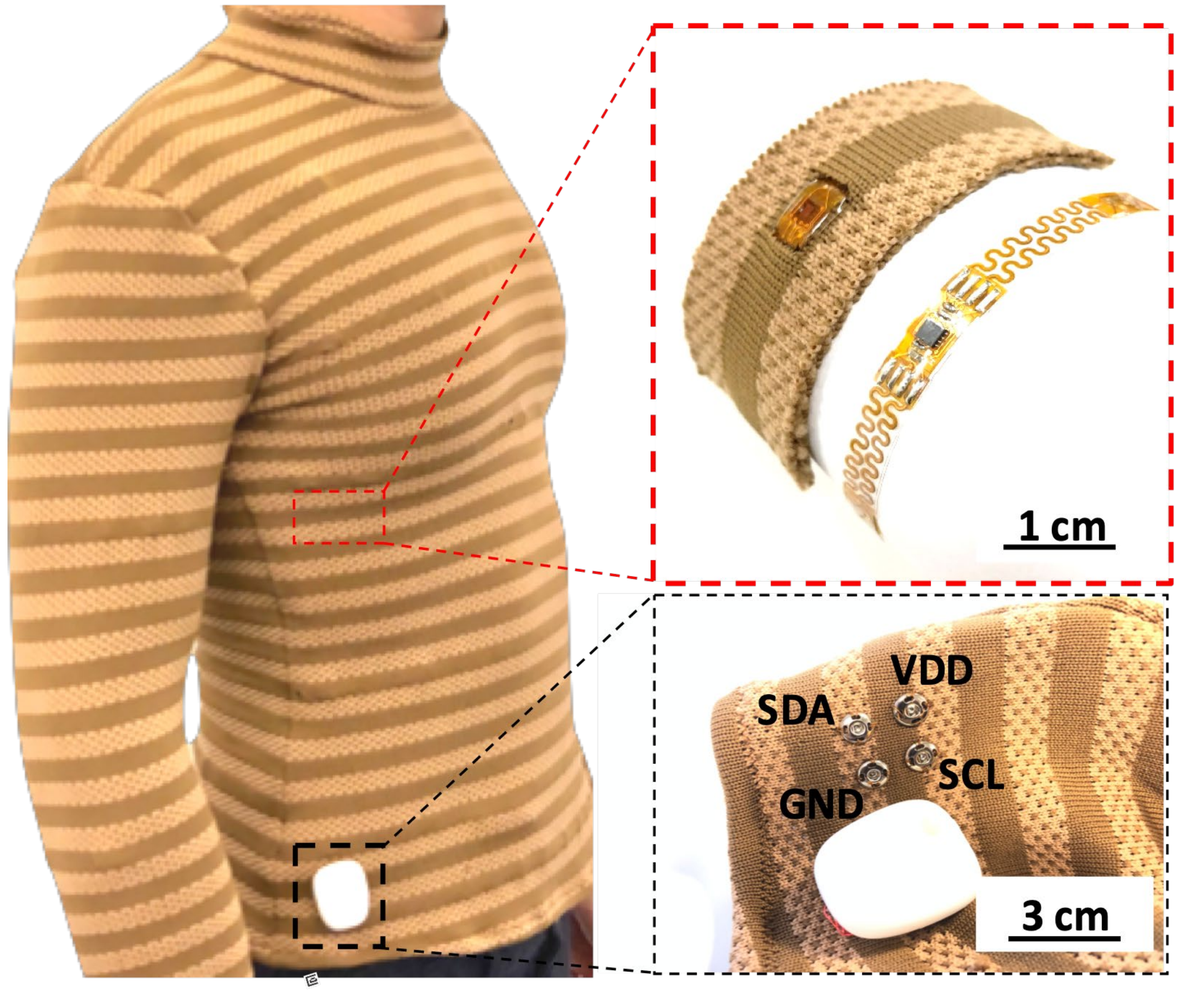
E-TeCS: Electronic Textile Conformable Suit

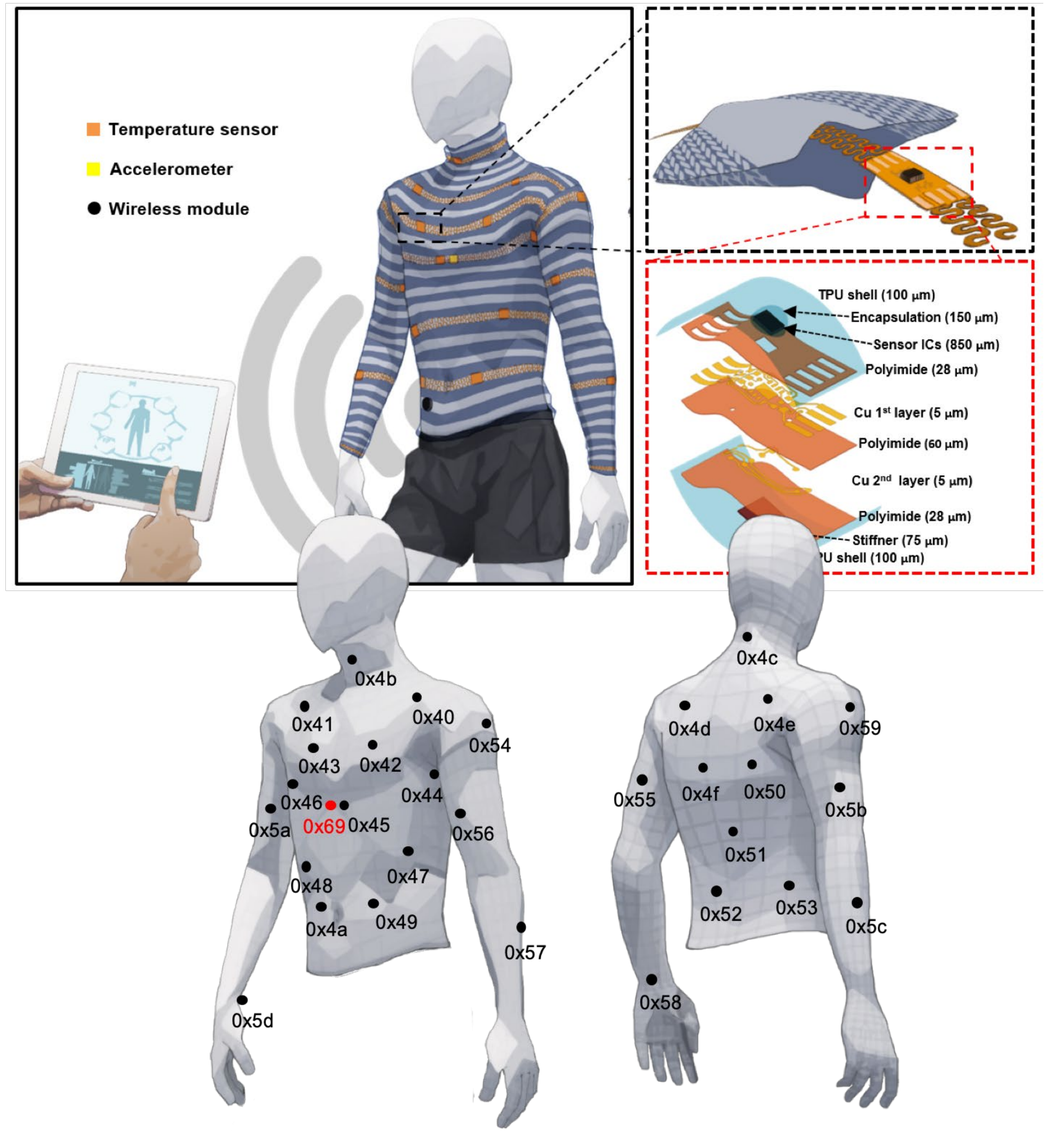




Wicaksono, Tucker, Sun et al., E-TeCS, *in Nature Flex. El.* (2020)

E-TeCS: Electronic Textile Conformable Suit

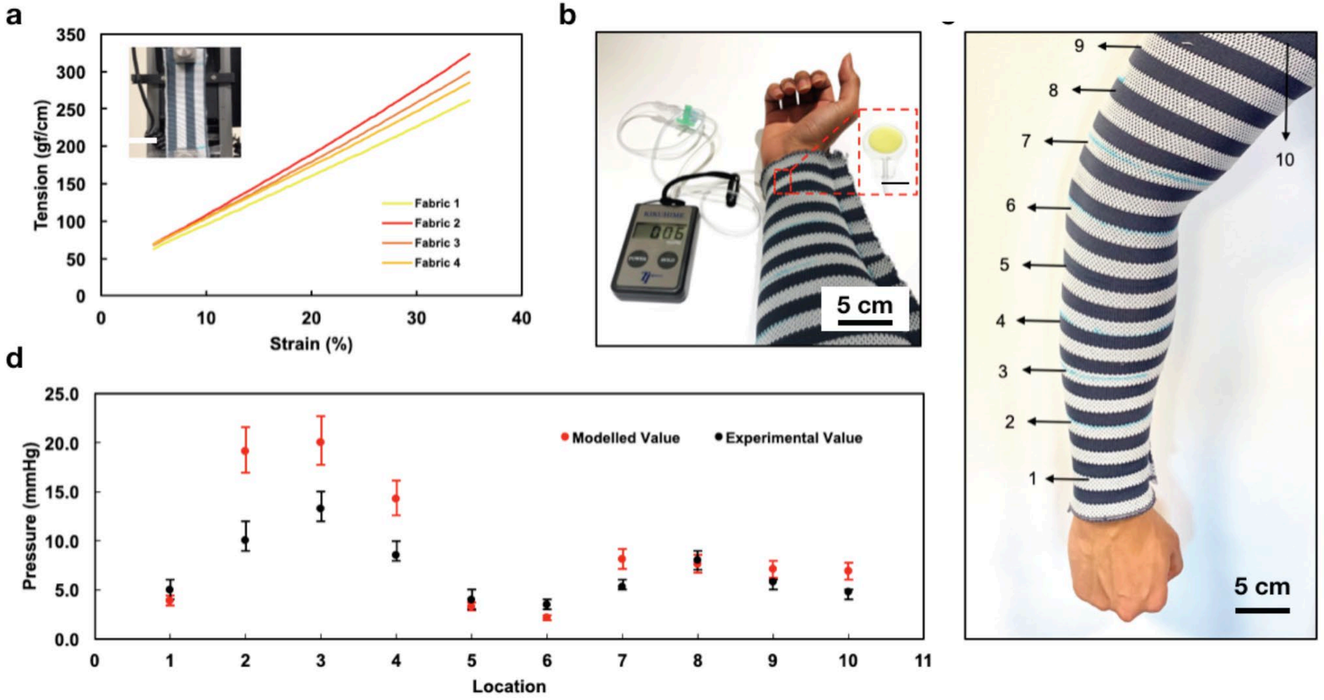


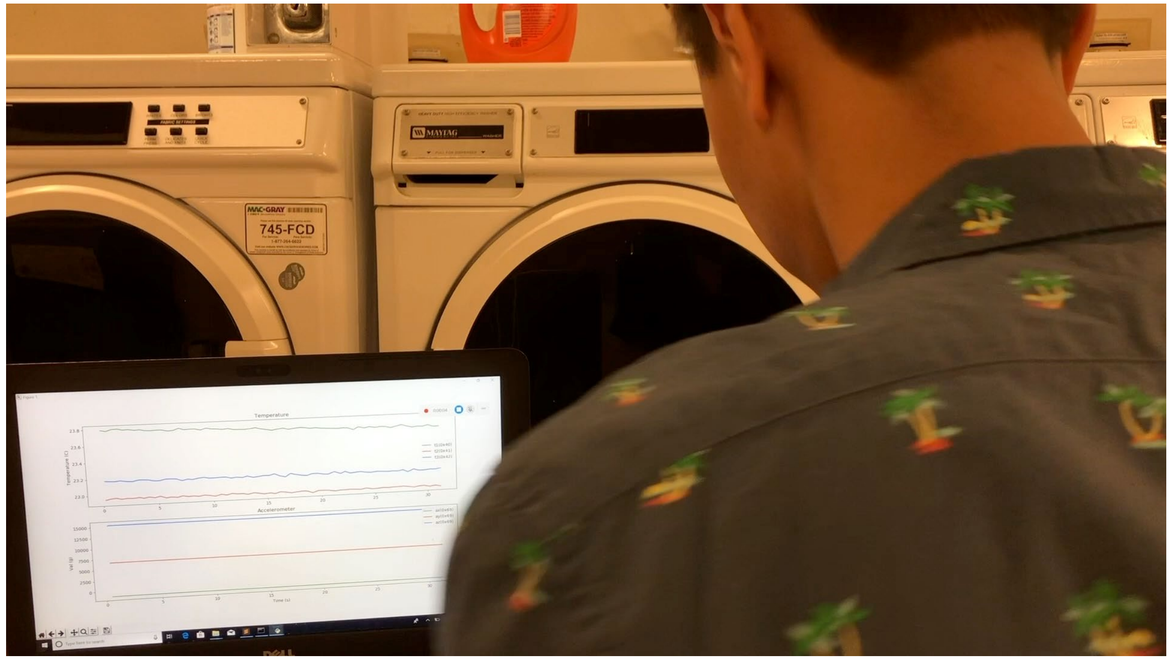


Wicaksono, Tucker, Sun et al., E-TeCS, *in Nature Flex. El.* (2020)

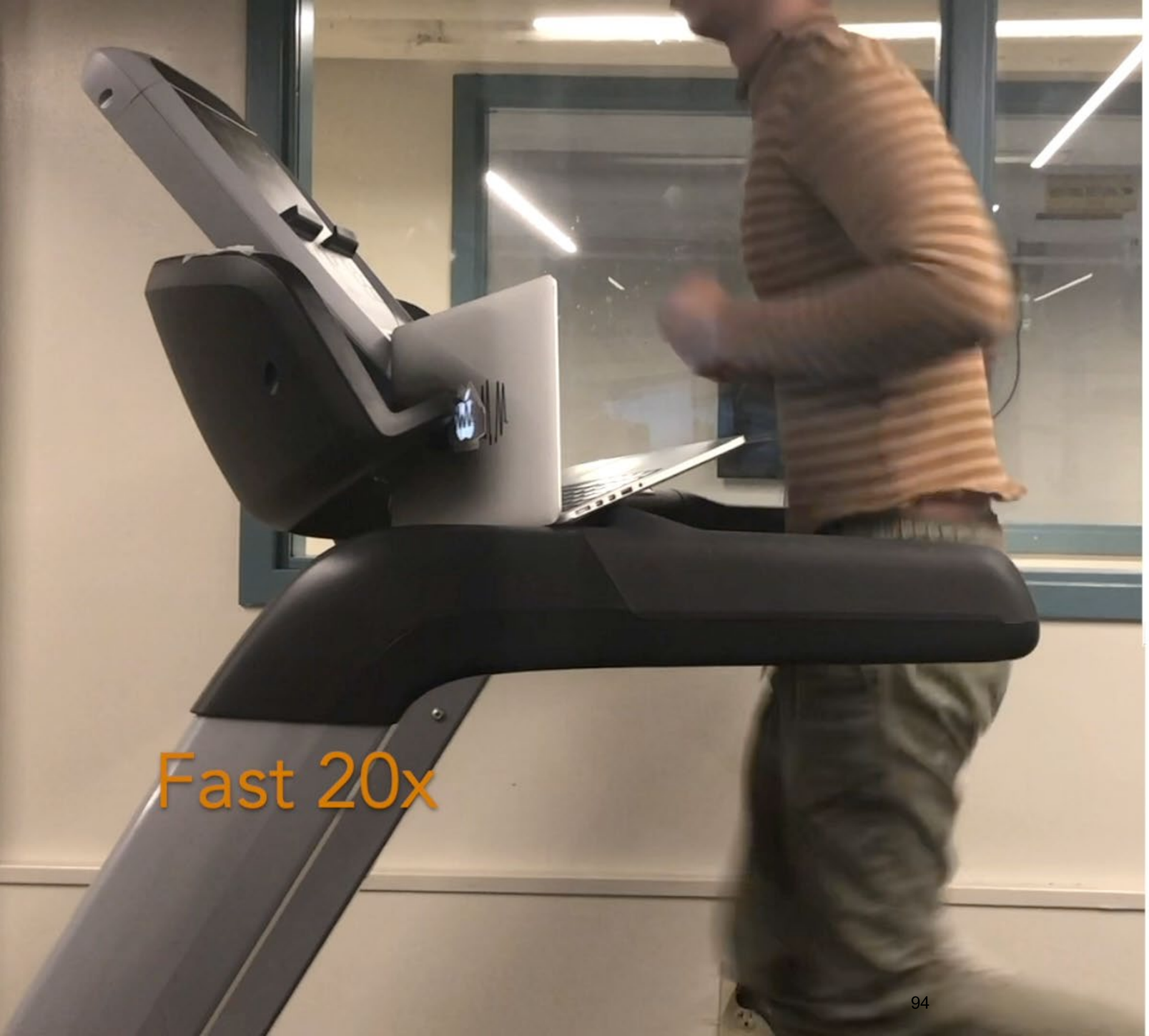
E-TeCS: Compression modelling and washability study

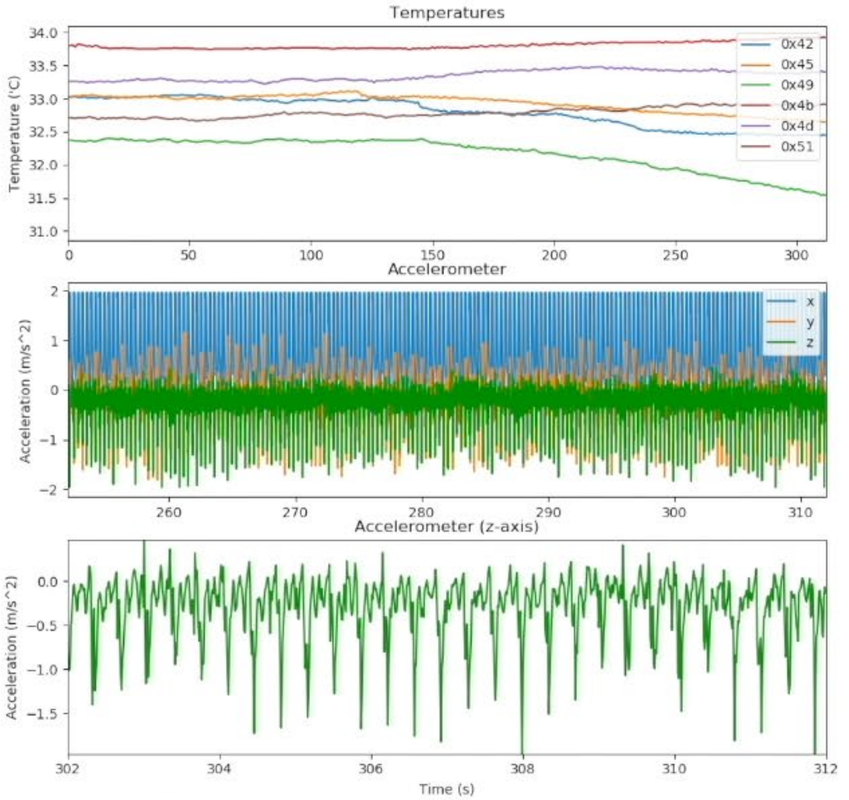
(Compression Pressure) $$P = \frac{2\pi El(CF)}{C_{body}} \frac{Re}{1 - Re}$$

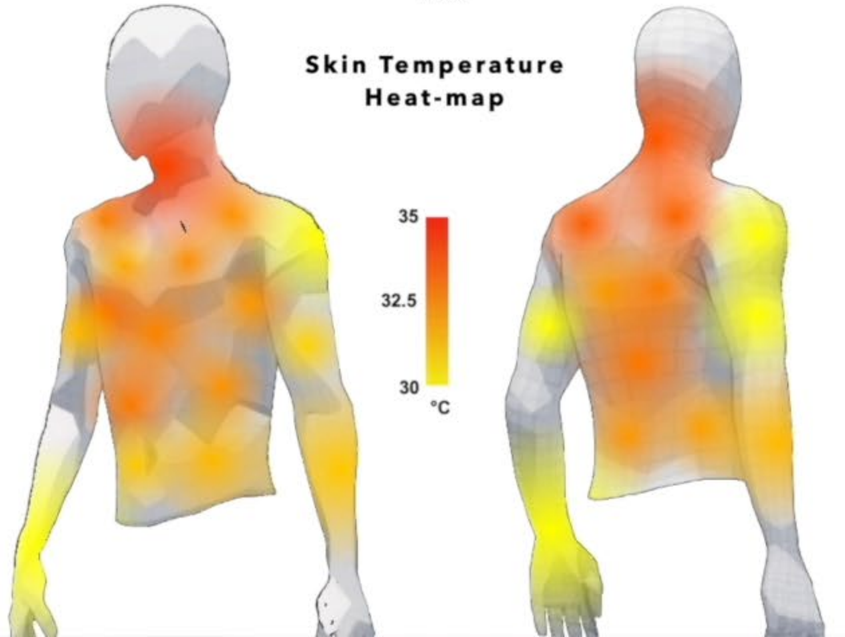




Wicaksono, Tucker, Sun et al., E-TeCS, *in Nature Flex. El.* (2020)


Fast 20x

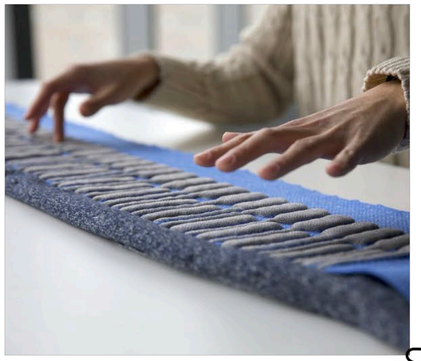

Temperatures
Temperature (°C)
0x42
0x45
0x49
0x4b
0x4d
0x51
Accelerometer
Acceleration (m/s^2)
x
y
z
Accelerometer (z-axis)
Acceleration (m/s^2)
Time (s)


Skin Temperature
Heat-map
35
32.5
30
°C

Architecting sensate fabrics across scales

Objects

60 touch + 5 stretch + 1 pressure
Capacitive and piezoresistive array
72 connections

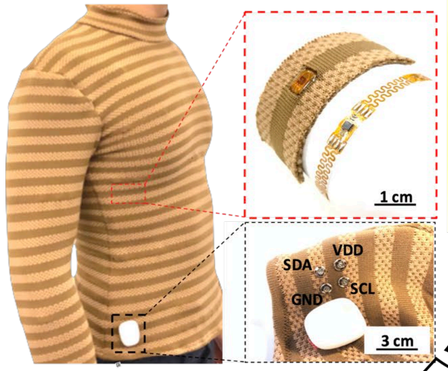


KnittedKeyboard
Musical expression

Body

31 temperature + 1 accelerometer
I2C sensor nodes
4 connections

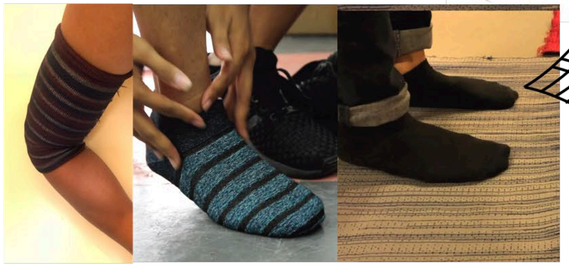
12 x 8 pressure-sensing pixels
Piezoresistive matrix
20 connections



E-TeCS
Physiological sensing
Physical activity monitoring

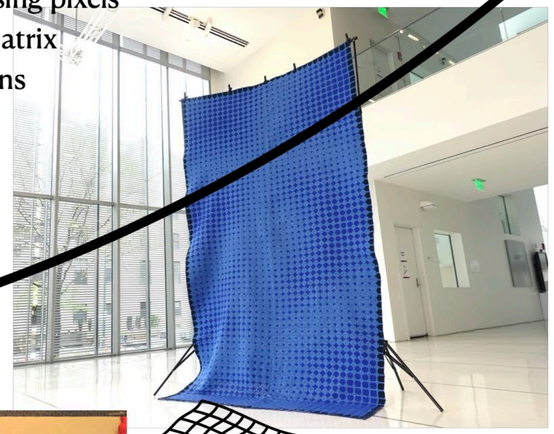
Room-scale

30 x 60 pressure-sensing pixels
Piezoresistive matrix
90 connections



3DKnITS
Activity recognition
Biomechanics

13 Tx and 12 Rx antennas
Active capacitive/e-field
25 connections



Tapis Magique
Interactive dance

Building

Living Knitwork Pavilion
Immersive environments
Telepresence

Toward Electronic Textile Gaia

Wicaksono, Cherston, and Paradiso. *IEEE Pervasive Computing*, 2021.

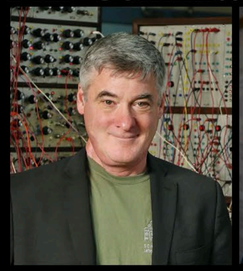
Toward Electronic Textile Gaia

Wicaksono, Cherston, and Paradiso. *IEEE Pervasive Computing*, 2021.

Krebs Cycle of Creativity III
Neri Oxman (2020)

Thanks a ton!

PhD Committee


Dr. Joseph A. Paradiso
Responsive Environments


Dr. Alexander Stolyarov
AFFOA


Dr. Svetlana Boriskina
MIT MechE


Dr. Kris Pister
UC Berkeley

SM Committee


Dr. Canan Dagdeviren
Conformable Decoders


Dr. Hiroshi Ishii
Tangible Media


Dr. Rosalind Picard
Affective Computing

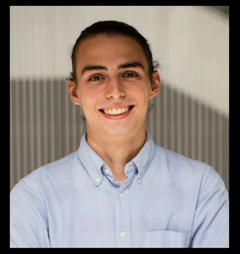
<Collaborators>

Musician, Sound Artists


Dr. Don Derek Haddad
Responsive Environments


Mike Jiang
Viral Communications


Jordan Rudess
Dream Theater


Lancelot Blanchard
Responsive Environments


Manaswi Mishra
Opera of the Future

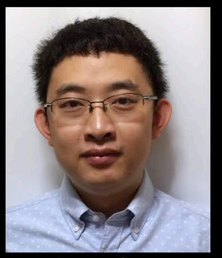
Engineers, Scientists, Designers


Dr. Dava Newman
Media Lab, MIT+Harvard HST


Dr. Artem Dementyev
Google Deepmind

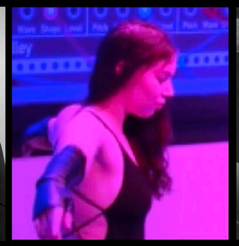

Fangzheng Liu
Responsive Environments


Gabriela Advincula
City Science


Dr. Tao Sun
Virginia Tech

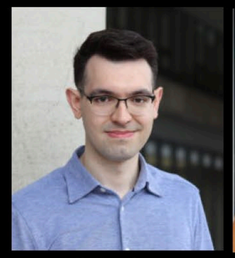
Choreographer, Dancers


Loni Landon
Dance Company

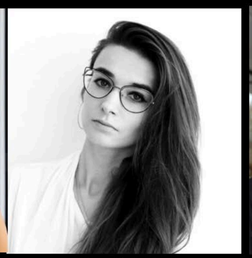

Nina Gentile

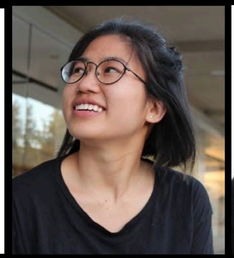

Pichet Klunchun
Dance Company

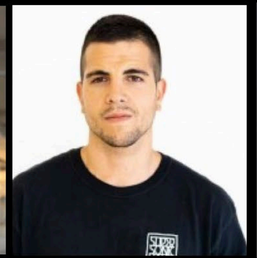

Treyden Chiaravallotti
Harvard GSD

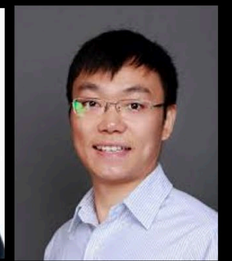

Ali Shtarbanov
Responsive Environments


Dr. Juliana Cherston
Harvard CfA


Judy Cichoka
FabLab Poland


Sam Chin
Responsive Environments


Alfonso Parra Rubio
Center for Bits and Atoms


Dr. Wei Yan
Donghua University

+ many others (UROPs, Media Lab, MIT SA+P, Phage, BM Community)

Indonesian Contemporary Arts and Design, Jakarta 2022

Ben Shahn Center for Visual Arts, New Jersey 2024

With Pichet Klunchun Dance Company, Bangkok 2022

Intersect by Lexus, Tokyo 2021

See you next year!

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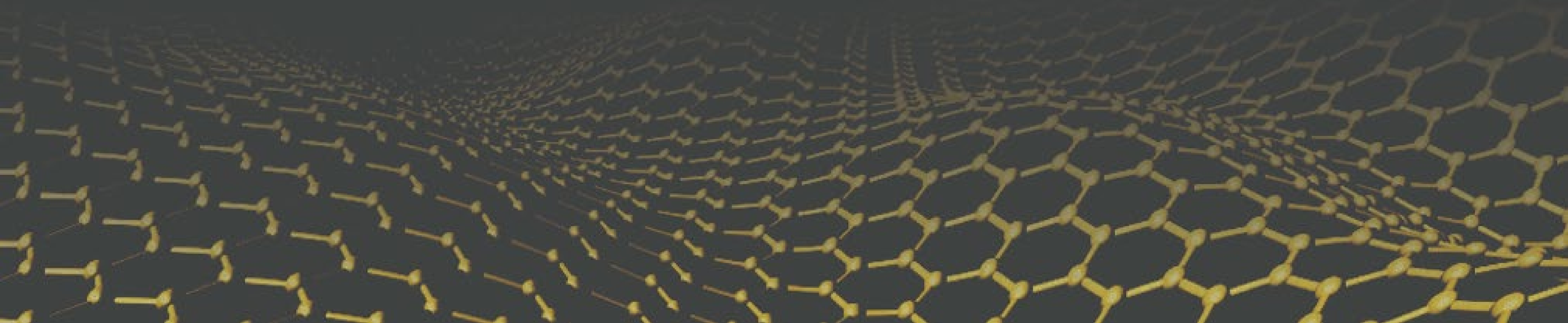
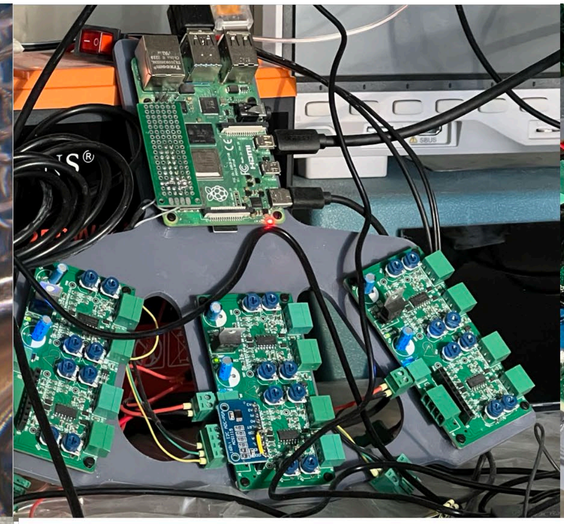
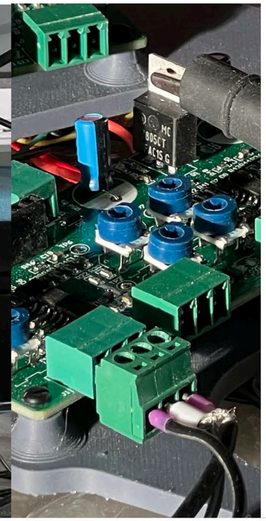
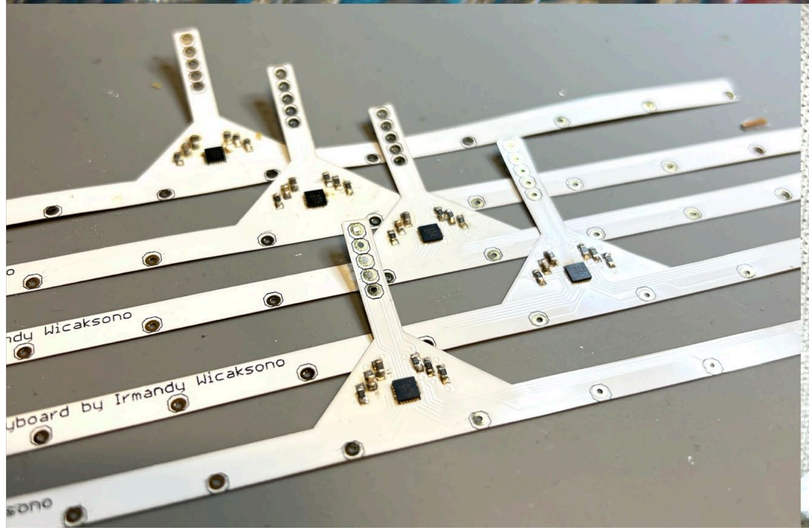
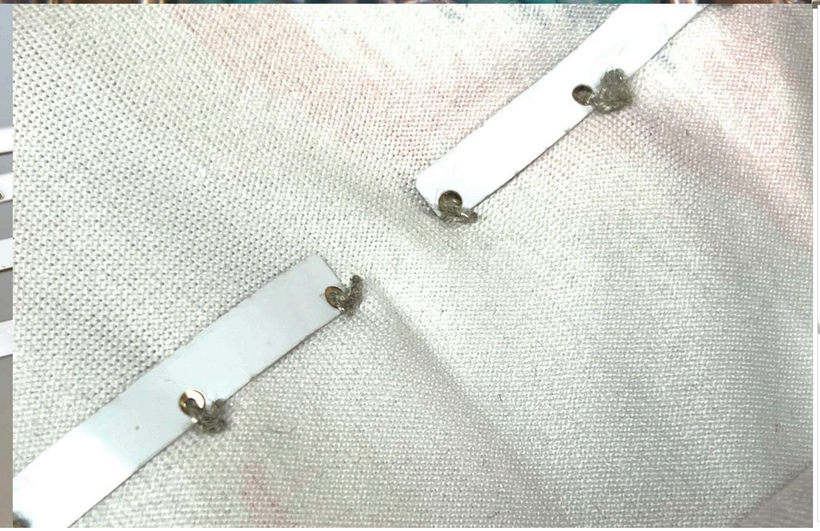


Soft-Hard Interfaces/Connectorization

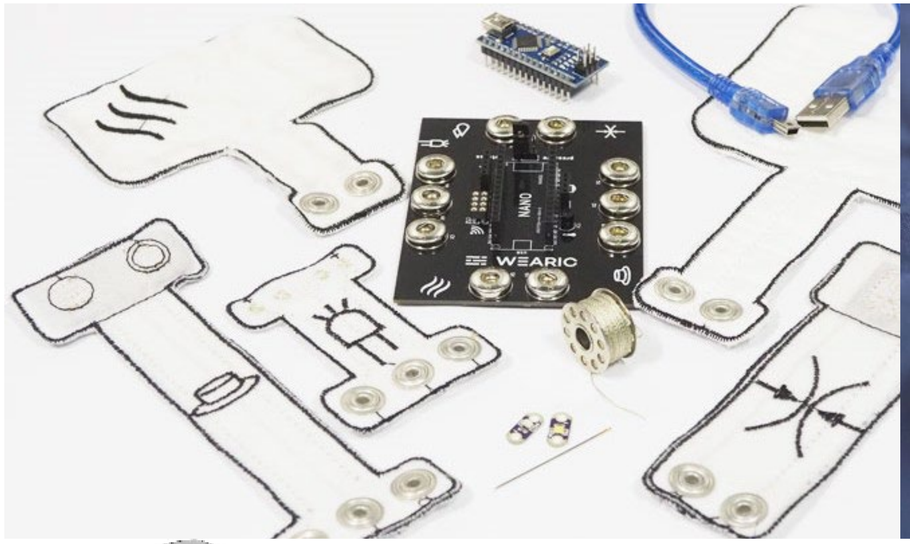


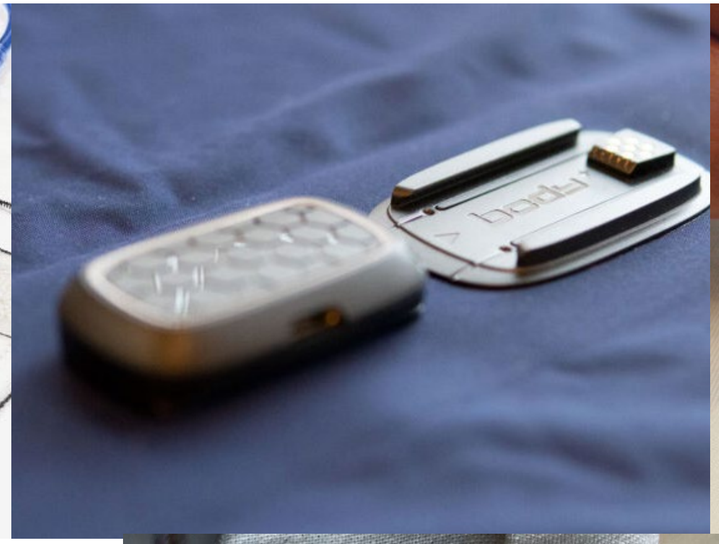


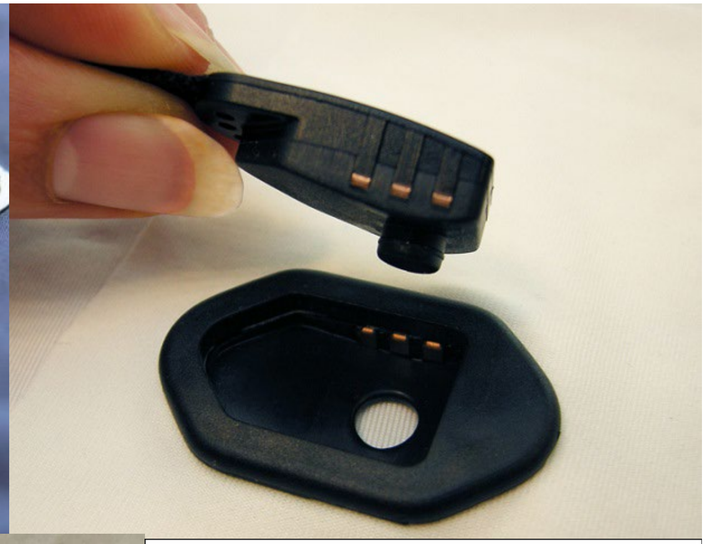


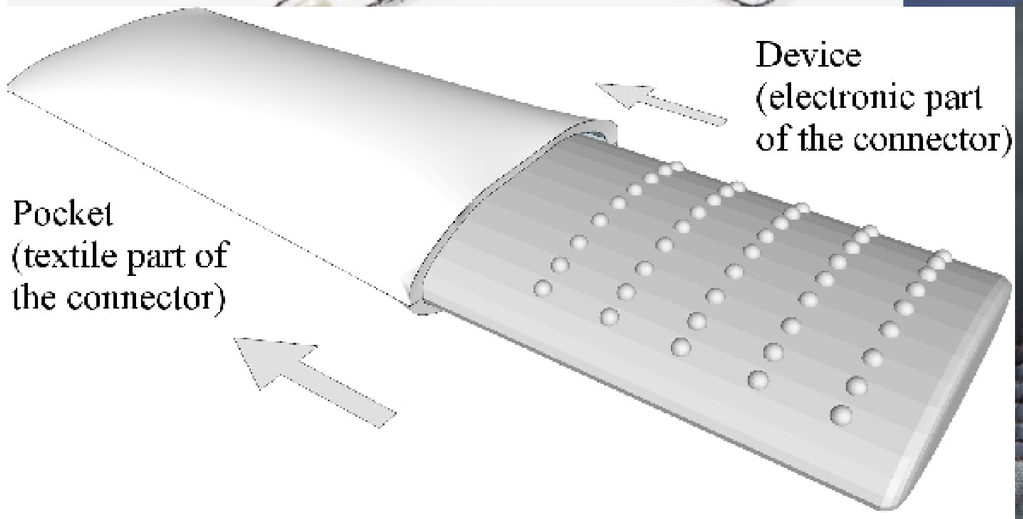


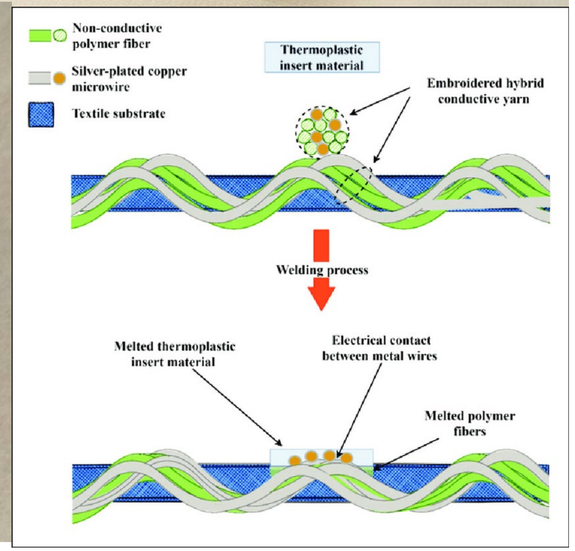
Soft-Hard Interfaces/Connectorization











Stanley, J., Hunt, J.A., Kunovski, P. and Wei, Y., 2022. A review of connectors and joining technologies for electronic textiles. *Engineering Reports*, *4*(6), p.e12491.

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