Tapis Magique: Machine-knitted Electronic Textile Carpet for Interactive Choreomusical Performance and Immersive Environments

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ABSTRACT

Tapis Magique is a pressure-sensitive, knitted large-scale electronic textile carpet that generates three-dimensional sensor data based on body location, postures, and gestures and drives an immersive sonic environment in real-time. Inspired by traditional textile arts and cultures, we applied an artistic approach into technological textile design and merged new materials, sensing technologies, and digital fabrication with contemporary dance and music into one united and harmonious piece of object and performance. In this pictorial, we present and discuss our textile design rationale, fabrication strategies, hardware systems, musical mappings, as well as our collaborative effort with a professional dancer to demonstrate the interactive electronic textile carpet. Our work challenges the conventional relationship between choreography and music and unveils dancer and/or sound artist's creative possibilities of agency, intimacy, and improvisation over the choreomusical performance through a novel textile interface.

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Interactive surface; smart textiles; choreography; musical mapping; knitted sensors.

CSS Concepts

• Human-centered computing ~ Human computer interaction (HCI) ~ Interaction techniques ~ Gestural input

INTRODUCTION

Ancient textiles have played a major role in the social, economic, and religious structures of communities around the world. Iconic, indigenous clothes are imbued with unique designs and patterns [1]. Some are believed to have magical powers and designed to carry specific meanings and wishes. Often complementing traditional dance and music, these textiles amplify a sense of community, identity, and expression.

Recently, new smart materials and digital fabrication technologies have modernized and pushed forward textile design, fabrication, and applications. Textile's physical and functional properties can now be tuned at the resolution of a fiber, a loop structure, or a particle coating [2]. These textiles can be fully customized from the micro to macro-scale and computationally designed and fabricated to form a seamless and multi-functional skin. Patterns, forms, colors, texture, thickness, elasticity, breathability, conductivity, and other parameters can be engineered through fiber structures or material choices. In this project, we leveraged the additive manufacturing process of machine knitting, polyester, synthetic mink, luminous, and electrically-conducting yarns to develop large-scale, seamless interactive textile sensate surface that we call *Tapis Magique*. The *tapis* indeed not only serves for aesthetic, comfort, and insulation purposes, but is also augmented as a responsive skin that bridges the tactile-physical with the immersive-digital world especially for interactive performance.

Demonstrating an organic and expressive relationship between choreography and music has been a never-ending feat in the performance arts, as seen in previous work by Cage and Cunningham, Horst and Graham, or Stravinsky and Balanchine [3]. *Tapis Magique* explores the creative interplay between art and technology and highlights the deep emotional link between contemporary textiles, dance, and music through the physical-digital connection. It provides a canvas for dancers, choreographers, and sound artists to program and compose their choreomusical pieces and push their limits of experimentation. It also creates an auditory-gestural synesthetic environment that invites and encourages dancers and audiences to express themselves with the *tapis*, as they experience a magical, embodied interaction and liveness that stimulates their body, hearing, and mind.

RELATED WORK

> "*When the music and dance create with accord... their magic captivates both the heart and the mind*",
>
> Jean-Georges Noverre

Choreography and Music

Body movements and gestures allow us to communicate, experience, and perceive each other and the world. Choreographers and dancers rely on these movements and gestures to create and express their art and intention. Dance and music have traditionally been two complementary art forms, with Ballet as an example tracing back to the Italian Renaissance in the 15th century [4]. However, their bi-directionality and seamless integration have been challenging and a growing research topic in contemporary practices [3].

Choreography is often rehearsed based on a musical piece. A dancer typically conforms to a predetermined routine or repertoire, leaving limited space for agency and improvisation over both the visual and audio components. Integrating technology into an interactive performance would thus introduce and augment new forms of expression and allow dancers to gain more agency and become an integral part of music-making through the mediation of sensors and computers [5].

Interactive Dance Technology

Ballets Russes by Diaghilev and Stravinsky in 1917 is an early demonstration of interactive performance that involves choreography, lighting, and objects played on a scenodynamic stage [6]. Another early example of a musical instrument exploring the direct relationship between movement and sound is a Theremin, invented by Leon Theremin around the 1920s [7]. *The Odyssey of Variations V* by Cage, Cunningham, and Collaborators in 1965 is also a prominent example of the deep integration of music, dance, and technology, with dancers influencing the audio and visual directly through a dozen of photoelectric cells and analog electronic sound mixing systems by Max Matthews and Bell labs and five high capacitive antennas for proximity sensing developed by Robert Moog [8]. At the time, the performance was a successful cross-pollination and collaborative effort between composers, dancers, visual artists, and hardware engineers.

As electronics became more miniaturized and new sensing modalities became available. There has been a great interest in detecting human gestures for new kinds of performance or musical expressions. The Digital Dance Project used the Big Eye, a video camera with a software application that could recognize movement, acceleration, and position through image processing and send standard Musical Instrument Digital Interface (MIDI) messages to trigger sound and modulation [5]. Palindrome Intermedia Performance Group also developed a similar process with their EyeCon video and movement tracking and analysis system [9]. The sound mapping and synthesis in their *Seine hohle Form* performance were done in real-time through a Max/MSP environment.

In another form factor, Miburi is a commercial wearable musical instrument consisting of a vest with capacitive sensors, two hand grips, a pressure sensor-embedded shoe, and a belt acting as a processing unit [10]. Researchers have also come up with other methods, such as embedding a suite of sensors (such as PVDF, force-sensitive resistor, inertial measurement units, bend sensors, and capacitive electrodes) into a shoe [11], gloves [12,13] and dance costumes [14] or embedding piezoelectric cables into a carpet [15]. Since accelerometers and cameras have become more accessible, miniaturized, and advanced, we have also seen many interactive performances or even commercial products involving these technologies [16-17]. Other work such as the SKIN project, have looked further at the physical activity of the dancers and the inner physiological signals or biometric data, such as heart rate, respiration, temperature, humidity, and muscle activity as input parameters [18]. Yamaha engineers with dancer Kaiji Moriyama have also applied back muscle sensing through distributed electromyography (EMG) and leveraged artificial intelligence to convert the sensor data into MIDI messages to control a Disklavier piano and pedal in real-time, as demonstrated in their concert *Mai Hi Ten Yu* [19].

Electronic Textiles for Interactive Media and Environments

Some of the early developments of electronic textiles (e-textiles), in the form of a musical jacket and a set of pressure-sensitive musical balls, were demonstrated in the late 20th century [20,21]. Since then, many e-textile musical controllers and installations had emerged, leveraging their rich texture, tactile feel, and deformability for expressions [22-24]. However, most current e-textiles work still involves hand-sewing and manual techniques or embedding rigid electronics into textile structures.

Project Jacquard is an example of work that tried to bring electronic textile to the masses using industrial weaving techniques [25]. The capacitive touch matrix developed here acts as a gestural controller that can control a phone or music by swiping through the sleeve of a jacket. As digital knitting machines become accessible to researchers, other knitted textile interfaces such as SensorKnits [26], KnittedKeyboard [27], and KnitUI [28] also attempted to incorporate conductive threads into knitting structures to fabricate capacitive and resistive sensing textile. Other researchers have also explored intrinsic knitting structures and conductive polymer coating to seamlessly develop resistive or capacitive stretch sensors around the joint angles to monitor physical gestures for interactive performance [29]. However, the scale and form factor of these knitted e-textiles are still relatively small. We have yet to see seamless interactive knitted textiles that leverage an industrial knitting machine's rapid, large-scale output [30].

DESIGN AND IMPLEMENTATION RATIONALE

As textiles are highly deformable and palpable materials, they are a great candidate for physical interfaces. There are three common methods of pressure sensing in e-textiles, using capacitive, piezoelectric, or resistive-based sensing. The capacitive approach consists of a spacer fabric in-between two conductive layers. This approach tends to be finicky, as it suffers from parasitic capacitance and environmental noise and requires grounding layers [31]. Piezoelectric fibers can also be used to detect vibrations; however, it does not measure continuous pressure and could only work for impact detection [32,33]. We chose to develop piezo-resistive e-textile as it does not require complex interface circuits, is robust against electromagnetic noise, and also low-cost [34,35]. Having a rollable, programmable interactive textile surface instead of wearable devices possesses several advantages. It is less cumbersome and more versatile for dancers as they can wear their typical performance costume, and it also allows sensing multiple dancers without adding more complexity. The limitation is that sensing only happens around the active region, though this should not be a problem since performance is typically situated within a stage.

Textile Pattern

The most frequently applied approach to develop knit or weave patterns or motifs is through mathematical models (such as Boolean and algebra) or parametric and generative methods [36, 37]. Multiple efforts have been conducted to connect music with textiles by mapping musical scores and notations into 2-D weave patterns [36] or *vice versa*, transforming traditional textile unique and meaningful patterns into a sonic experience [38]. Other tangentially relevant textile designs touching the literal artistic inspiration of this work are the *Fabric of the Universe* [39] and *Listening Space: Satellite Ikat* [40], in which 3-D astrophysical simulation was fed into a digital weaving machine to create a large-scale cosmic web textile installation and real-time audio intercepts of satellite data were decoded visually and used as knitting patterns respectively.

Cultural traditions have also been a source of inspiration for textile developments. Our design approach is inspired by various traditional cultures such as Javanese and Balinese gamelan [41,42] and Maharashtra folk dance [43] that deeply connected their textile arts and traditional clothing to their dance and music. These cultures give personal values and a sense of shared identity to their own textile patterns, which is currently lacking in technological textile design. The traditional textiles' symbols, patterns, and other visual metaphors represent deep and meaningful relationships between humans, nature, animals, and the universe. The visual aspects, particularly traditional textile pattern, proportion, balance (order and disorder), and irregularity, have also been argued to resemble typical musical structures and compositions [44].

Our artistic textile pattern is motivated by the overarching theme of our collective performance, which is *musica universalis* or *the music of the spheres* [45] through both *Venus Sunrise* and *Biotic-Abiotic Interactions* choreomusical pieces. The row-column matrix represents a space-time grid that touches the principle of general relativity. Gravitational force is critical in the *Tapis Magique* workings. We are constantly sensing the exerted force due to our change of balance, gestures, and center of mass on the carpet amplified by gravity. On top of the grid that informs our sensor resolution, we applied geometrical patterns of the celestial stars and circles as planetary bodies to guide the dancers and choreographers of the sensor locations throughout the tapis. We leveraged parametric design to distribute the change of size of these circles and stars and create a swirl illusion, illustrating the multi-dimensionality of the universe. This multi-dimensionality also corresponds to the large spatiotemporal or 3-D sensor data that consist of x and y positions and z pressure values.

Besides functioning as visual cues or coordinates, the dynamic textile pattern in *Tapis Magique* could also be individually mapped to challenge our cross-modal perception and explore the relationship between sound and shapes or visual signifiers [46]. Finally, the brushstroke details in the tapis background represent the universe's density and complexity.

DIGITAL KNITTING APPROACH

In this work, we leverage digital knitting techniques using flat-bed knitting machines with thermoforming techniques to realize a seamless piezo-resistive matrix e-textile carpet that are able to detect spatiotemporal 3D pressure across the surface. This approach allows rapid and large-scale manufacturing of interactive sensing textile with a customizable aesthetic, as well as tunable electrical and mechanical properties through fiber choices and knitting structure.

Knitting Program

The digital knitting programming interface consists of two grid sections (see Figure 1 in the next page with the knitting machine block program based on our e-textile carpet design). The left grid area (Figure 1a-b) is used to develop the shape and pattern of the knit fabrics through x-y color block programming, where each color and sign represents a specific knit instruction. The right grid area (Figure 1c), on the other hand, defines machine parameters for each line such as the yarn carrier number, knitting speed, and stitch tension. Each color on the left grid represents a different knit operation. Since we used flat-bed knitting machine with two machine beds, most of the operations involve switching from the front to the back knit. We first started with a low-level color block-programming that enable abstraction and simplification from a knitting machine-readable instruction format. With instruction library (Figure 1d), we can then convert the low-level pattern into a line-to-line front and back knit instructions that the knitting machine can process.

The dense geometrical patterns of the stars scattered around the brushstroke details on the *tapis* represent 1800 pressure-sensing pixels and are inspired by the galactic space. Parametric design transformed these patterns into a 3D spatial illusion to illustrate the multi-dimensionality of the sensor data. It resonates with *"Venus Sunrise,"* one of our performance pieces that presents a metaphorical celestial sound of the universe as the dancer is twirling around the stars, traveling through space and time.

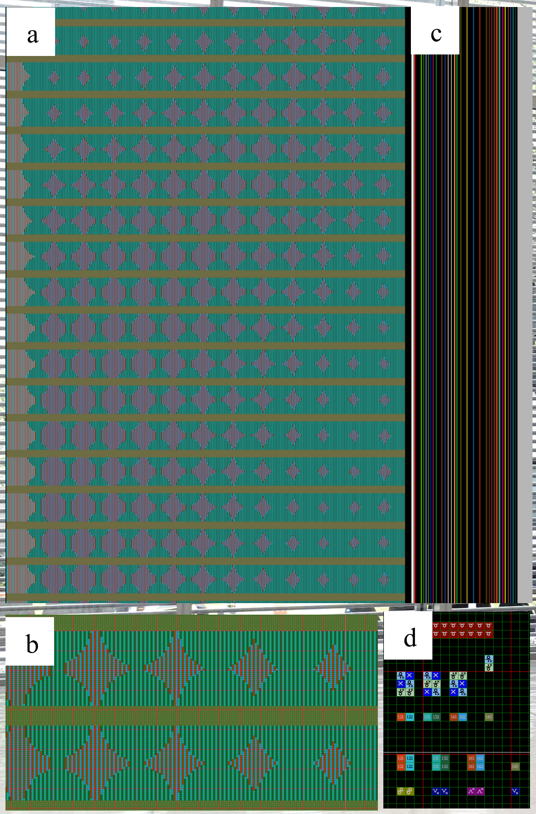
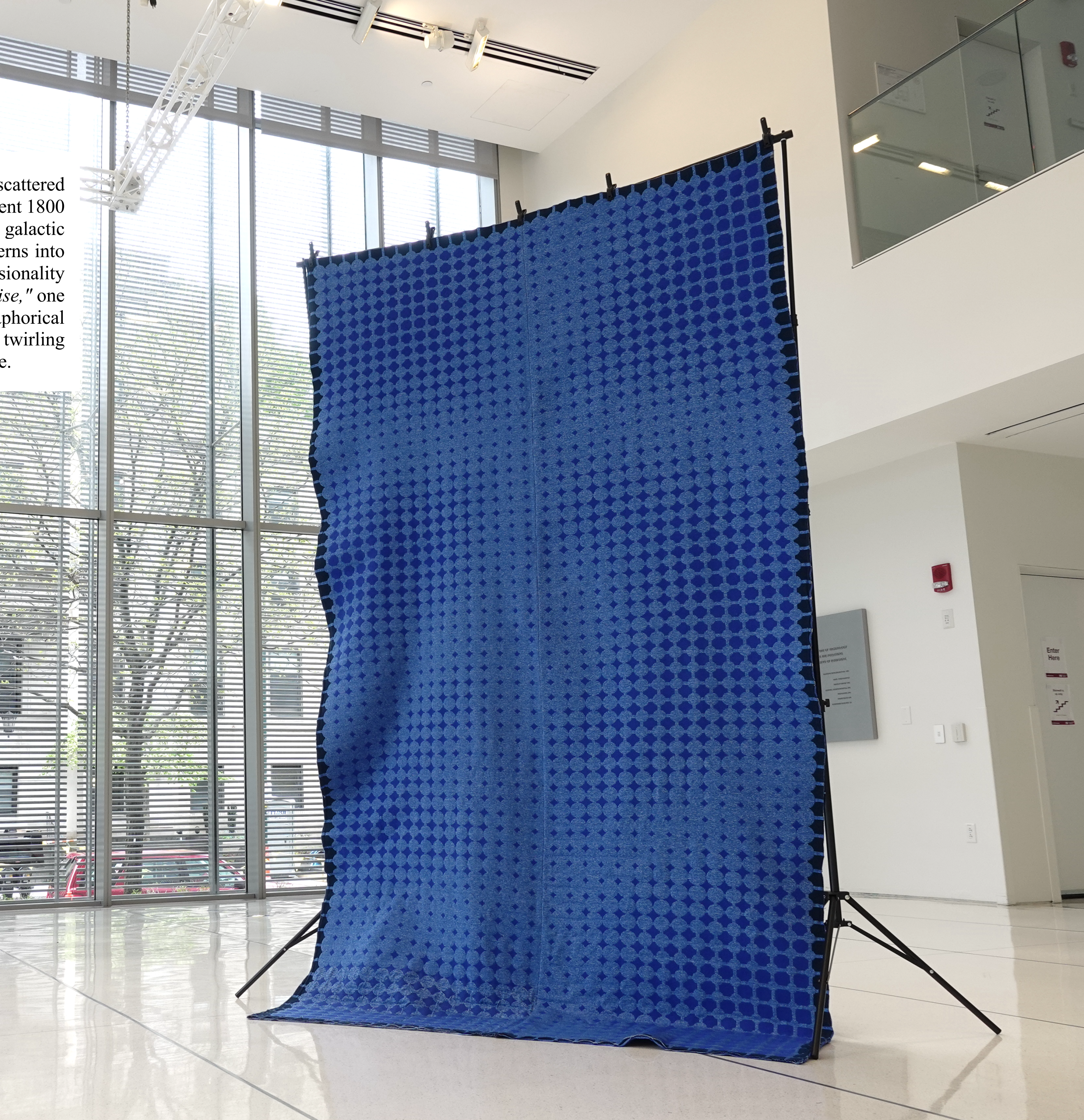


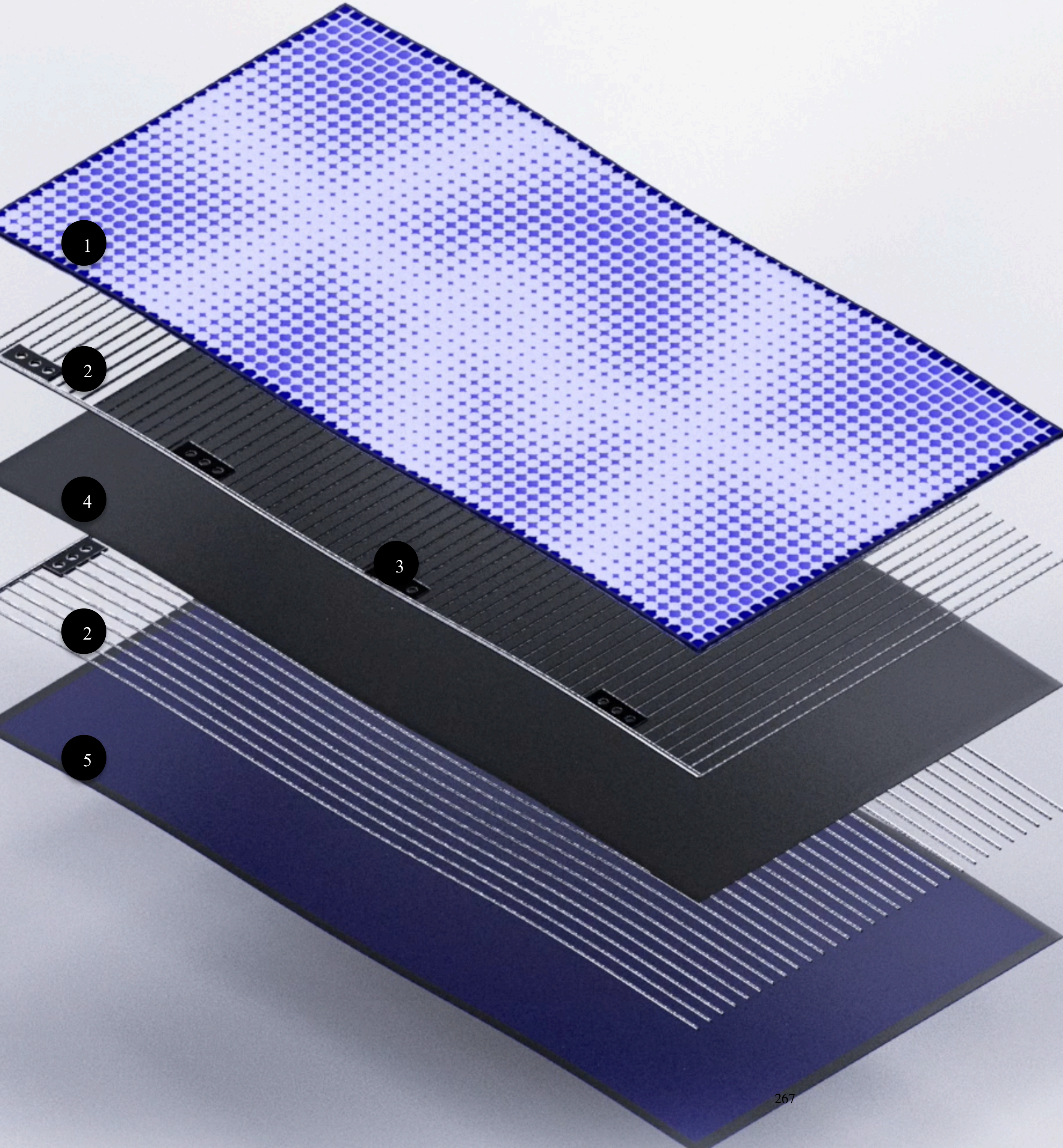
Figure 1: Knitting block program for *Tapis Magique*



MATERIALS AND FABRICATION

The *tapis* design is composed of multi-layer knitted textiles. The top and bottom layers are orthogonal conductive line matrices knitted within a single operation using multi-material twisted yarns. The middle layer is a knitted piezo-resistive textile, a pressure-sensitive layer that interfaces with the conductive matrices to create a sensing grid. The piezo-resistive layer consists of PPy-coated polyester knit fabric This layer exploits the piezoresistive effect, and mechanical pressure applied to the material induces a change of its electrical resistance which is constantly read by the conductive layers. The outer skin of our carpet, spanning 3m in length and 1.5m in width, was fabricated in two runs and sewn together in the middle due to the width limit of the knitting machine. The fact that both top and bottom conductive knitted lines are inward-facing and insulated by the outer layers avoids possible shorts and parasitic impedance from the environments.

The furry textures from the synthetic mink yarns provide a soft tactility for physical feedback and give an intimate and comforting feel of the *tapis*. The thermoplastic fibers were then steamed to melt the multi-layer knitted textiles into one rigid surface, giving it structural reinforcements. In addition, the outer-facing textile glows in the dark from the luminous yarns, bringing out the starry effects for night performance.



SYSTEM DESIGN

The knitted conductive lines are connected to a system hardware consisting of multiplexers, shift-registers, operational amplifiers, and microcontroller that sequentially reads each pressure sensing pixel and sends it to a computer. These pixels collectively generate continuous 3D spatiotemporal sensor data mapped into Musical Interface Digital Instrument (MIDI) streams to trigger and control discrete notes, continuous effects, and immersive soundscapes through science-inspired musical tools. We used Teensy 3.6 as our main microcontroller with 35ms or ~30 Hz of read-out frequency for sending 1800 pixels of 12-bit pressure sensor data to the computer. We leveraged the in-built Teensy USB MIDI library or Hairless-MIDI Serial Bridge to convert these sensor data to readable formats for musical mapping and sound synthesis through Max/MSP, Ableton Live, or VCV Rack.

EXPLODED VIEW

1. Mink, Luminous, High-Flex Polyester, and Melting Yarns Top Knit
2. Conductive and High-Flex Polyester Yarns Matrix (30x60) Knit
3. Multiplexing Interface Hardware Circuits
4. Piezoresistive Knit
5. High-Flex Polyester and Melting Yarns Base Knit

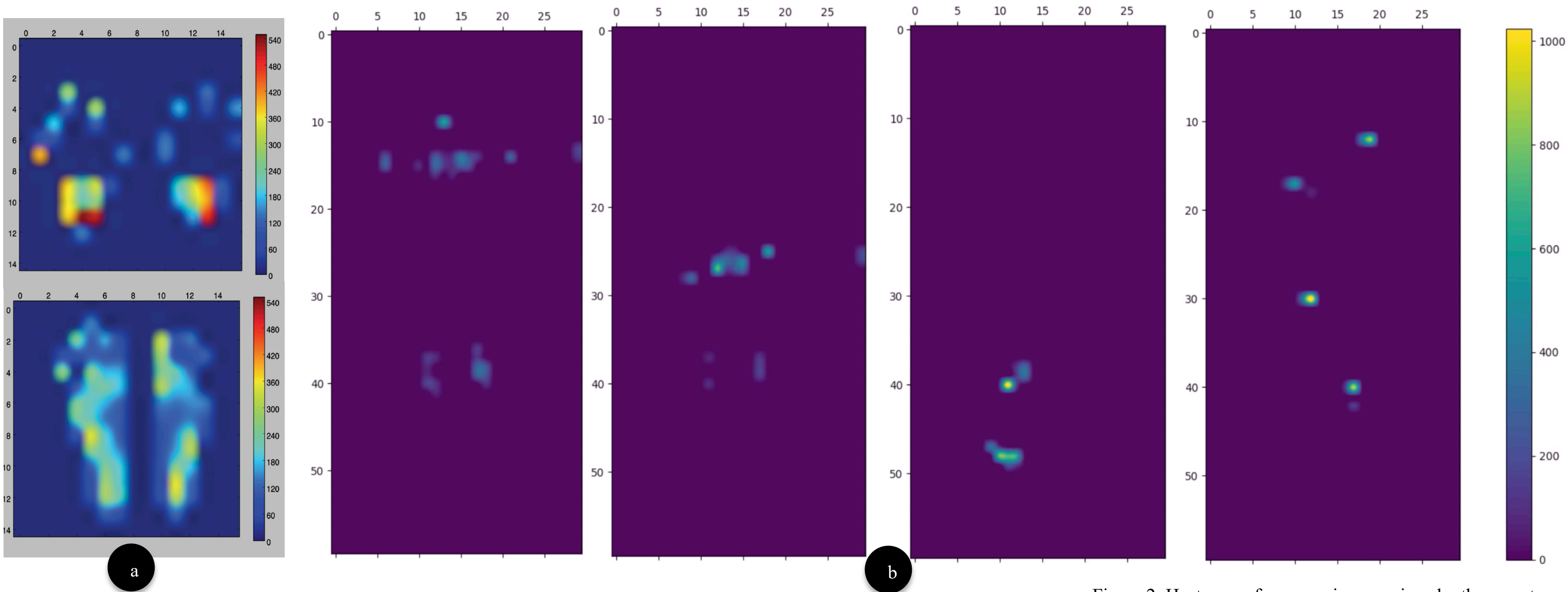


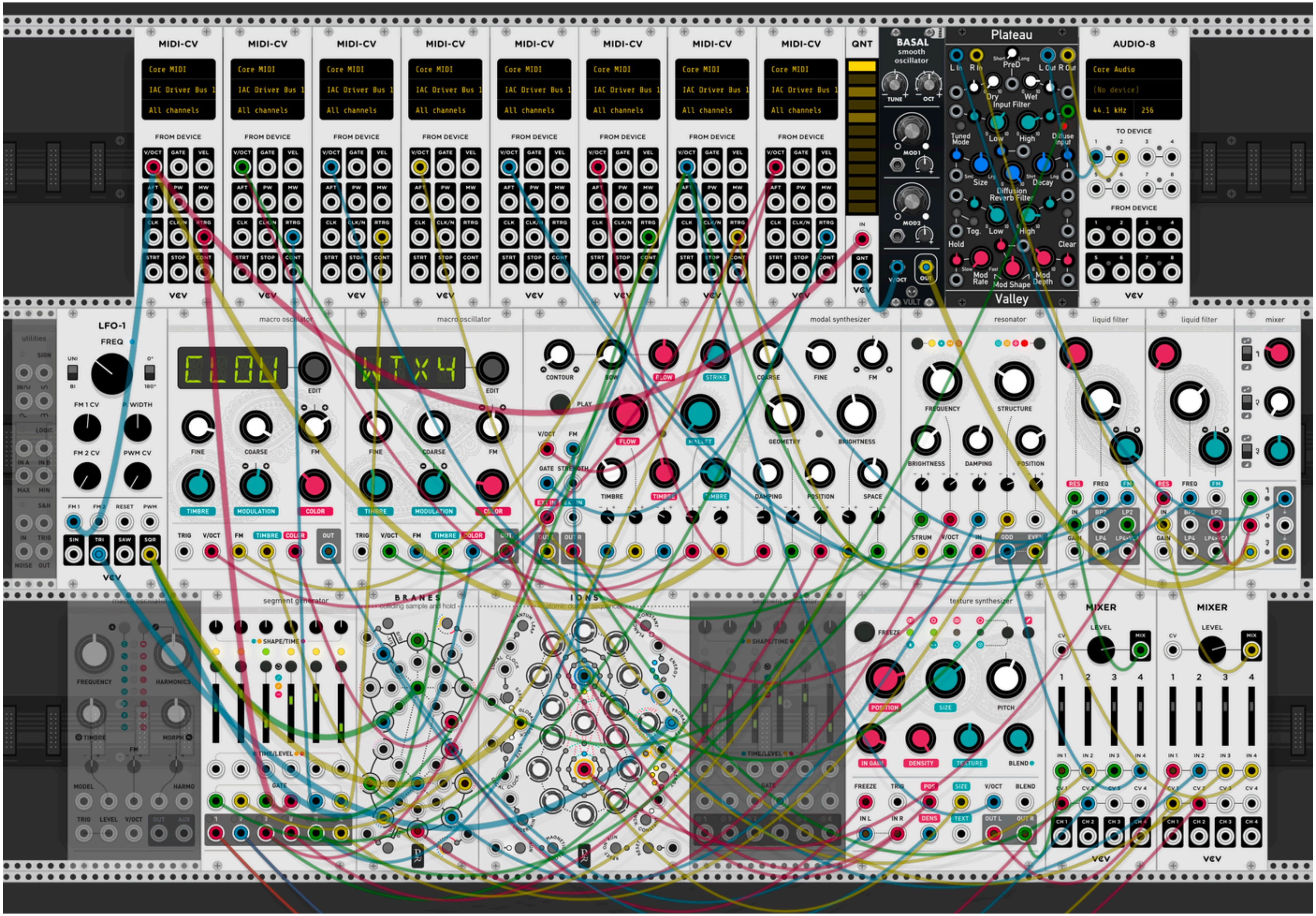
Figure 2: Heat-map of pressure images given by the carpet

SENSOR DATA

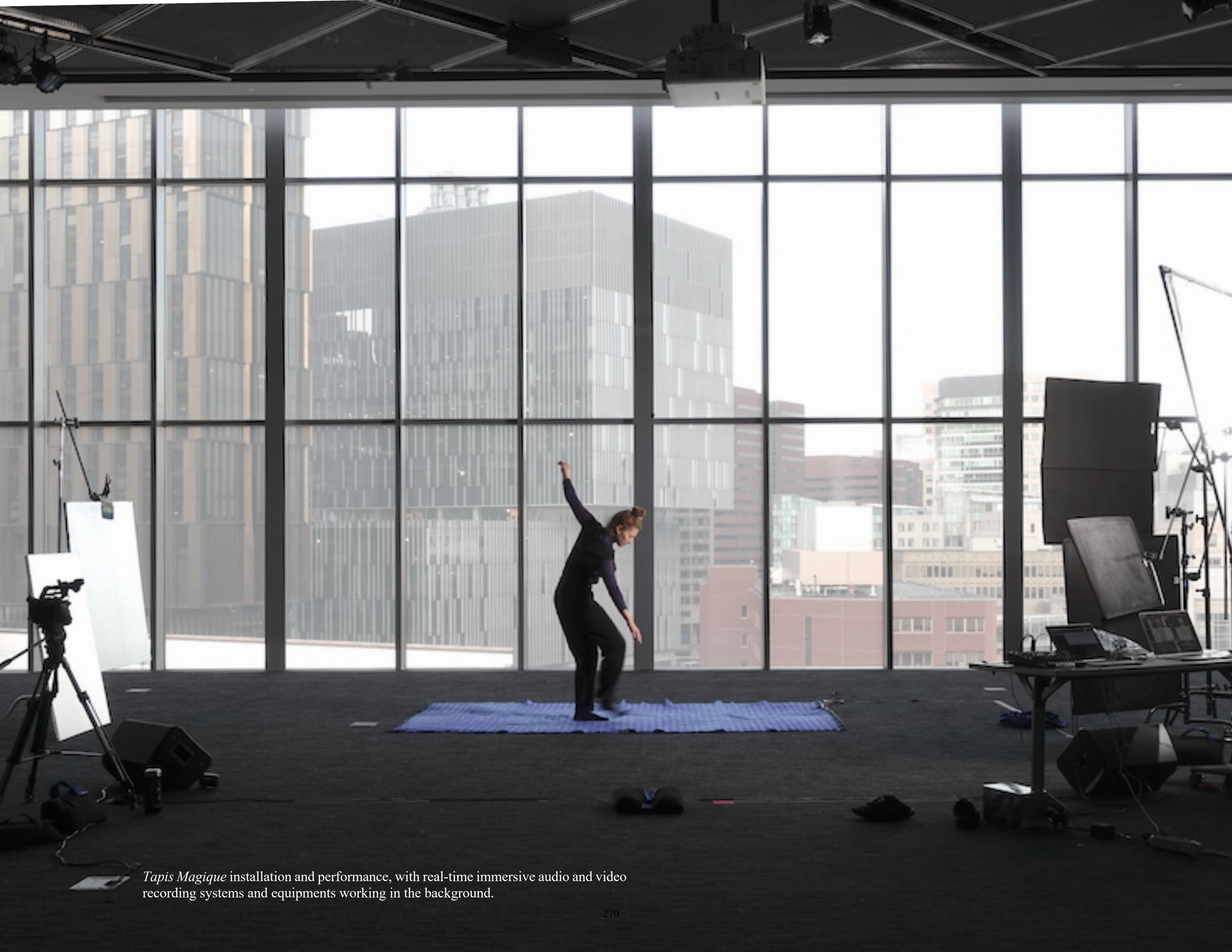
As we balance and redirect our center of mass through our feet, we exert force on the grounds. By detecting the pressure distribution of the feet through the e-textile carpet, we can extract rich contextual information about the dancer's location, gestures, or even postures [47,48] (our feet pressure distribution change slightly as we move our other body parts), as well as sense how hard the dancer hits or presses against the carpet.

Figure 2a shows a higher resolution version of the carpet (2.5 cm pitch). In this mat, we can see clearly the pressure distribution of the feet and hands to infer activities or interactions with the surface.

Figure 2b presents multiple pressure images of the carpet as the dancer (from right to left) laid down on its surface, tried to get up, stood on her feet, and crawled.



VCV Rack Synthesizer Modules/Patches for “*Venus Sunrise”* Performance



Tapis Magique installation and performance, with real-time immersive audio and video recording systems and equipments working in the background.

CHOREOMUSICAL MAPPING AND SYNTHESIS

To create an emotionally-engaging experience for both the dancer and audience, we adapted five interactive dance principles by Gonzalez, Caroll and Latulipe [49].

- The direct and indirect mapping should be done in such a way that the audience could intuitively be able to understand that the dancer triggers the sound and modulation.
- The carpet should give the dancer a new degree of autonomy and musical expression.
- The music and the choreography should create a united, harmonious, and integrated experience.
- The intensity of the musical mapping or the sonic environment should be in sync with the choreography.
- The technologist and sound artist should be involved in the choreographic and musical mapping process and work side-by-side with the dancer and choreographer.

Curating a complex mapping for 1800 incoming MIDI notes in a 30x60 grid was made possible using the virtual modular synthesizer platform VCV Rack. The incoming stream of MIDI data is first fed into quantizer modules that align the notes to major, minor, and pentatonic scales, as well as mystic chords. Several patches were designed to invoke various emotions while being played by a professional choreographer, creating a sonic landscape, ready to be explored in an unreplicable experience. Using a virtual synthesizer provided by a flexible modular interface accommodates a much wider range of musical mapping [50,51].

Excerpt images of the *Biotic-Abiotic Interactions* and *Venus Sunrise* performance

Four different ideas were picked for this mapping, navigating themes ranging from space exploration, micro-organisms and biological interactions, film noir and cinematic landscape, and others. Depending on each theme, a quantizer module sets the musical scale of the overall patch accordingly. The patches also feature a finite state machine sequencer, complex oscillators, granular synthesis, physical modeling, as well as subtractive synthesis, all glued with stacks of digital spatiotemporal effects.

The light intensity guides the brightness of the mapping in the room; for instance, major and pentatonic scales were selected in a patch called *Venus Sunrise* during the day. During the nighttime, darker themes were picked, governed by minor scales and the infamous mystic chord in a piece called *Biotic-Abiotic Interactions*. Please see our accompanying video and link to watch these interactive, choreomusical performances [52].

DISCUSSIONS AND REFLECTIONS

This project is intended to spark discussions and explore the relationship between textiles, dance, and music. It is not in its final stage and as such, will require further explorations in musical mapping and choreography. We have learned a tremendous lesson by collaborating with a contemporary dancer.

In terms of musical mapping and user experience, we have learned that the combination of direct and indirect mapping, blurring notes, and soundscapes are more artistic and desirable than a straightforward, direct mapping between movement and sound. The more responsive the carpet was, the more the dancer felt like she was a conductor, and that connection is crucial in designing an immersive experience. She felt this experience of being both a musician and a dancer in the night performance. During the day performance, she was too focused on her choreography and was drowned in the immersive experience that sometimes she forgot that she was the one controlling the notes and soundscape. There was an interesting and intimate synesthetic experience between the dancer's movement and proprioception and the auditory experience, as the dancer can "hear" her body moves.

From the audience's point of view, seeing the dancer interacts with a carpet sparks questions and curiosities. "Does the dancer move because she wants to make that sound?" or instead, "does the dancer move in response to the sound made by the carpet and synthesizer?". "Was the performance choreographed? or was it organic and an improv?". There was an interesting discussion about whether the carpet or the dancer predominantly drives the sound or whether it is a conversation between the dancer and the carpet. These ambiguous yet stimulating experiences have challenged the perspective of liveness and virtuality argued by Auslander and Phelan [53].

In future work, we are interested in exploring ways to enable the dancer to change between various musical mappings and to leverage the continuous pressure sensing data instead of only using location and foot strike or velocity as MIDI signals. Adding haptic capabilities to the carpet will also augment the overall experience. It will be interesting to involve other or multiple dancers and sound artists, as they will have their own interpretations. Instead of one musical mapping per performance, we could also develop a dynamic musical mapping that gradually changes its ambiance and parameters throughout the performance. We are currently exploring other musical patches and choreography with different genres and styles.

In the age of functional materials, digital fabrication, and immersive technologies, we are not only designing and developing textiles and other objects as material artifacts, but we are also beginning to redefine and reinvent their purpose as an intelligent-responsive skin, challenging the perceptions of materiality, their relationship with us as human, and the blurring dualities between material and immaterial; real and virtual [54-56].

CONCLUSION

To sum up, we have proposed a large-scale pressure-imaging textile for interactive dance using an industrial manufacturing approach of machine knitting. Our material choices, rapid fabrication, and digital design approach also enable full customization of sensing resolution and prototype form-factors based on the user's needs and requirements. We have designed an interface circuit that could read the spatiotemporal pressure data and map them into MIDI signals that drive a set of VCV rack synthesizers.

By working side-by-side with a sound artist and a contemporary dancer and choreographer, this multi-disciplinary collaboration resulted in the demonstration of multiple performances and musical mapping, showing the capability of *Tapis Magique*. Since the *tapis* is programmable, we can fuse contemporary music with traditional dance and *vice versa*, allowing dancers and sound artists to collaborate and experiment and push the boundaries between sound and movement, music and choreography. The *tapis* could also benefit other human-computer interaction and activity recognition applications such as kids' engagement in learning, musical therapy, elderly care, rehabilitation, sports science, robotics, and augmented and virtual reality.

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REFERENCES

[1] Margot Blum Schevill. 1996. The communicative power of cloth and its creation. *Textile Traditions of Mesoamerica and the Andes* (1996), 1–16.

[2] Irmandy Wicaksono, Juliana Cherston, and Joseph A. Paradiso. 2021. Electronic textile *gaia:* ubiquitous computational substrates across geometric scales. *IEEE Pervasive Computing* 20, 3 (2021), 18–29.

[3] Paul Mason. 2012. Music, dance and the total art work: choreomusicology in theory and practice. *Research in dance education*, *13*(1), pp.5-24.

[4] Barbara Sparti. 1996. The function and status of dance in the 15th-century Italian courts. *Dance Research*, *14*(1), pp.42-61.

[5] Wayne Siegel and Jens Jacobsen. 1998. The challenges of interactive dance: An overview and case study. *Computer Music Journal*, *22*(4), pp.29-43.

[6] Chris Salter. 2010. *Entangled: technology and the transformation of performance*. MIT Press.

[7] Albert Glinsky. 2000. *Theremin: ether music and espionage*. University of Illinois Press.

[8] Leta E. Miller. 2001. Cage, Cunningham, and Collaborators: The Odyssey of" Variations V". *The Musical Quarterly*, *85*(3), pp.545-567.

[9] Joseph Butch Rovan Robert Wechsler, and Frieder Weiss. 2001. Seine Hohle Form: artistic collaboration in an interactive dance and music performance environment. *Crossings: eJournal of Art and Technology*, *1*(2).

[10] Teressa Marrin and Joseph Paradiso. 1997. September. The Digital Baton: a Versatile Performance Instrument. In *ICMC*.

[11] Joseph Paradiso, Kai-Yuh Hsiao, and Eric Hu. 1999. Interactive music for instrumented dancing shoes. In *ICMC*.

[12] Laetitia Sonami. 2008. 2. The Lady's Glove.

[13] Thomas J. Mitchell, Sebastian Madgwick, and Imogen Heap. 2012. Musical interaction with hand posture and orientation: A toolbox of gestural control mechanisms.

[14] Aline Martinez *et al.* 2018. Smart textiles in the performing arts. In *Textiles, Identity and Innovation: Design the Future* (pp. 311-318). CRC Press.

[15] Joseph Paradiso *et al.* 1997. The magic carpet: physical sensing for immersive environments. In *CHI'97 Extended Abstracts on Human Factors in Computing Systems* (pp. 277-278).

[16] Ryan Aylward and Joseph Paradiso. 2006. Sensemble: a wireless, compact, multi-user sensor system for interactive dance. In *Proceedings of the 2006 conference on New interfaces for musical expression* (pp. 134-139).

[17] Danilo Gasques Rodriques *et al.* 2013. MotionDraw: a tool for enhancing art and performance using kinect. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems* (pp. 1197-1202).

[18] Sarah Fdili Alaoui. 2019. Making an interactive dance piece: Tensions in integrating technology in art. In *Proceedings of the 2019 on designing interactive systems conference* (pp. 1195-1208).

[19] Harun Zulić. 2019. How AI can change/improve/influence music composition, performance and education: three case studies. *INSAM Journal of Contemporary Music, Art and Technology*, *1*(2), pp.100-114.

[20] Maggie Orth, Rehmi Post, and Emily Cooper. 1998. Fabric computing interfaces. In *CHI 98 conference summary on Human factors in computing systems* (pp. 331-332).

[21] Gili Weinberg, Gili, Maggie Orth, and Peter Russo. 2000l. The embroidered musical ball: a squeezable instrument for expressive performance. In *CHI'00 extended abstracts on Human factors in computing systems* (pp. 283-284).

[22] Irmandy Wicaksono, I. and Joseph A. Paradiso. 2017. Fabrickeyboard: multimodal textile sensate media as an expressive and deformable musical interface. In *NIME* (Vol. 17, pp. 348-353).

[23] Alex Olwal *et al.* 2018. I/O Braid: Scalable touch-sensitive lighted cords using spiraling, repeating sensing textiles and fiber optics. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology* (pp. 485-497).

[24] Sara Mlakar *et al.* 2021. The Sound of Textile: An Interactive Tactile-Sonic Installation. In *10th International Conference on Digital and Interactive Arts* (pp. 1-3).

[25] Ivan Poupyrev *et al.* 2016. Project Jacquard: interactive digital textiles at scale. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (pp. 4216-4227).

[26] Jifei Ou *et al.* 2019. SensorKnit: Architecting textile sensors with machine knitting. *3D Printing and Additive Manufacturing*, *6*(1), pp.1-11.

[27] Irmandy Wicaksono and Joseph Paradiso. 2020. Knittedkeyboard: Digital knitting of electronic textile musical controllers. In *Proceedings of the International Conference on New Interfaces for Musical Expression*.

[28] Yiyue Luo *et al.* 2021. KnitUI: Fabricating interactive and sensing textiles with machine knitting. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (pp. 1-12).

[29] Sophie Skach*et al.* 2018. Embodied interactions with e-textiles and the internet of sounds for performing arts. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction* (pp. 80-87).

[30] Irmandy Wicaksono *et al.* 2020. A tailored, electronic textile conformable suit for large-scale spatiotemporal physiological sensing in vivo. *npj Flexible Electronics*, *4*(1), pp.1-13.

[31] Jan Meyer, Paul Lukowicz, and Gerhard Troster. 2006. Textile pressure sensor for muscle activity

and motion detection. In *2006 10th IEEE International Symposium on Wearable Computers* (pp. 69-72). IEEE.

[32] Juliana Cherston and Joseph A. Paradiso. 2019. SpaceSkin: development of aerospace-grade electronic textile for simultaneous protection and high velocity impact characterization. In *Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2019* (Vol. 10970, pp. 111-125). SPIE.

[33] Wei Yan *et al.* 2022. Single fibre enables acoustic fabrics via nanometre-scale vibrations. *Nature*, pp.1-8.

[34] Patrick Parzer *et al.* 2016. FlexTiles: a flexible, stretchable, formable, pressure-sensitive, tactile input sensor. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (pp. 3754-3757).

[35] Jung-Sim Roh *et al.* 2011. Robust and Reliable Fabric, Piezoresistive Multitouch Sensing Surfaces for Musical Controllers. In *NIME* (pp. 393-398).

[36] Radostina A. Angelova. 2017. Design of weave patterns: when engineering textiles meets music. *The Journal of The Textile Institute*, *108*(5), pp.870-876.

[37] Gillian Smith. 2017. Generative design for textiles: Opportunities and challenges for entertainment AI. In *Thirteenth Artificial Intelligence and Interactive Digital Entertainment Conference*.

[38] Egidija Medeksaite. 2016. *Mapping Textile Patterns into Sonic Experience* (Doctoral dissertation, Durham University).

[39] Benedikt Diemer and Isaac Facio. 2017. The fabric of the Universe: exploring the cosmic web in 3D prints and woven textiles. *Publications of the Astronomical Society of the Pacific*, *129*(975), p.058013.

[40] Afroditi Psarra and Audrey Briot. 2019. Listening Space: Satellite Ikats. In *Proceedings of the 23rd International Symposium on Wearable Computers* (pp. 318-321).

[41] Phillip Kitley. 1992. Ornamentation and originality: involution in Javanese batik. *Indonesia*, (53), pp.1-19.

[42] Urs Ramseyer. 1988. Music, dance, and the textile craft in Bali. *Visual Anthropology*, *1*(3), pp.323-333.

[43] Manorma Sharma. 2007. *Musical Heritage of India*. APH Publishing.

[44] Gabriel Pareyon. 2011. *On Musical Self-Similarity: Intersemiosis as Synecdoche and Analogy*. Gabriel Pareyon.

[45] Jean- Pierre Birat. 2017. Musica Universalis or the Music of the Spheres. *Matériaux & Techniques*, *105*(5-6), p.509.

[46] Irmandy Wicaksono *et al*. 2018. PerForm: Deformable Interface for Exploring Sound through Shapes. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems* (pp. 1-6).

[47] Yiyue Luo *et al.* 2021. Learning human–environment interactions using conformal tactile textiles. *Nature Electronics*, *4*(3), pp.193-201.

[48] Irmandy Wicaksono *et al.* 2022. 3DKnITS: Three Dimensional Digital Knitting of Intelligent Textile Sensor for Activity Recognition and Biomechanical Monitoring. In *2022 44th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*. IEEE.

[49] Berto Gonzalez, Erin Carroll, and Celine Latulipe. 2012. Dance-inspired technology, technology-inspired dance. In *Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design* (pp. 398-407).

[50] Don Derek Haddad and Joseph A. Paradiso. 2019. The World Wide Web in an Analog Patchbay. In *NIME* (pp. 407-410).

[51] Leonardo Gabrielli. 2020. *Developing Virtual Synthesizers with VCV Rack*. Focal Press.

[52] MIT Media Lab. 2022. Tapis Magique: A Choreomusical Interactive Carpet. https://www.youtube.com/watch?v=h8DvpOKlJ1I

[53] Ivani Santana and Fernando Iazzetta. 2009. Liveness in mediatized dance performance-an evolutionary and semiotic approach. *Np: np, nd*.

[54] Richard Grusin. 2015. Radical mediation. *Critical Inquiry*, *42*(1), pp.124-148.

[55] Hiroshi Ishii. 2008.. Tangible bits: beyond pixels. In *Proceedings of the 2nd international conference on Tangible and embedded interaction* (pp. xv-xxv).

[56] Mikae Wiberg, Jofish Kaye, and Peter Thomas. 2014. PUC theme issue: material interactions. *Personal and Ubiquitous Computing*, *18*(3), pp.573-576.