Movement Matters: How a Robot Becomes Body

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ABSTRACT

This paper explores movement and its capacity for meaning-making and eliciting affect in human-robot interaction. Bringing together creative robotics, dance and machine learning, our research develops a novel relational approach that harnesses the movement expertise of choreographers and dancers to design a non-anthropomorphic robot, its potential to move and capacity to learn. The project challenges a common assumption that robots need to appear human or animal-like to enable people to form connections with them. Our performative body-mapping approach, in contrast, embraces the difference of machinic embodiment and places movement and its connection-making potential at the centre of our social encounters. The paper discusses the first stage of our research project, a collaboration with dancers to study how movement propels the becoming-body of a robot, and outlines our embodied approach to machine learning, grounded in the robot's performative capacity.

CCS CONCEPTS

• **Computer systems organization → Robotics** • *Computing methodologies → Learning from demonstrations* • Computing methodologies → Neural networks

ADDITIONAL KEYWORDS AND PHRASES

Dance, kinesthetic empathy, movement, non-anthropomorphic, machine learning, social robotics

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1 INTRODUCTION

In recent years, we have seen robots entering our everyday lives, in the form of complex toys, 'assistants' in therapy, eldercare and education, and 'companions' that offer entertainment at home. Hence, robots are increasingly presented as 'social actors', designed to assist and entertain humans in social environments [1,2,3]. As robots are assigned social roles that already exist in our society, their design usually aims to fit these previously human social tasks. The majority of research in Social Robotics and Human–Robot Interaction (HRI) thus focuses on anthropomorphic (humanoid) and zoomorphic robots [1,3]. The underlying assumption is that human- or pet-like appearance and behaviour helps us to form meaningful connections with them.

HRI studies, however, consistently show that the more humanlike a robot appears, the more people expect it to also have human-level cognitive and social capabilities, so that interacting with these apparently humanlike machines is often frustrating and disappointing [1]. From a posthumanist viewpoint, this ambition to build mechanical servants and companions in our own image promotes not only humans making connections with machines but also eliminating human/machine difference [4]. It could be argued that robots mimicking humans or pets, often in cute, caricatured ways, deliberately blur the difference between organic and mechanical bodies, and human and machine cognition, to elicit human investment based on superficial and often false social cues. Designs that don't rely on the familiarity of existing bodies, on the other hand, allow for human-machine encounters that aren't restricted by "preconceptions, expectations or anthropomorphic projections … before any interactions have occurred" [1].

In this paper, we explore an alternative approach to robot design and its capacities to learn and elicit responses, which aims to shift the focus from representational qualities to the performativity of human-machine configurations [see 5]. We believe movement and its connection-making, relational potential is key to both the becoming-body of a robot and its capacity to relate to other bodies and the world. It opens up a much wider range of possible robot morphologies and behaviours, based on machinic forms of embodiment that don't rely on mimicking familiar bodies.

Bringing together creative robotics, dance and machine learning, the project's enactive approach harnesses the movement expertise of choreographers and dancers to design a robot's non-anthropomorphic body, its potential to move and capacity to learn. Our aim for working with choreographers and dancers is not to render the robot more human but rather to investigate how sociomaterial relations are produced and activated and explore machine learning of these bodily relations and movement qualities. Rather than understanding the robot as a mechanical artefact, which must be implanted with social qualities, this approach enacts the robot as a sociomaterial phenomenon, placing movement at the centre of the encounter.

2 PERFORMATIVE BODY MAPPING

This section discusses our core methodology, called Performative Body Mapping (PBM), which harnesses dancers' movement expertise to shape a robot and its ways of learning to move and interact with the world. At the core of PBM is the development of an autonomous robot with an abstract, non-organic form and a capacity to learn how to move in ways that are unique to its own machinic body, while 'sensitive' to the subtle movement qualities it acquires from human dancers. The performative approach comprises four stages: bodying, grounding, imitation, and improvisation. The project is still in progress, and in this paper we examine the first stage, bodying [6] or the becoming-body of a robot, and how we 'found' abstract, non-organic forms by studying and reflecting upon the ways in which their movements can elicit interesting responses. This is followed by an outline of the remaining three stages that focus on our embodied approach to machine learning.

2.1 Entangling Dancer and Machinic Form

The first stage is concerned with the challenge of designing a robot's form in tandem with its movement capabilities. Commonly, it is the robot's functionality or social role that shapes its physical form, which inevitably manifests a number of assumptions about its ways of moving and bodily relating to the world. All too often, the robot's physical form is reduced to a mobile container, allowing its computational mind to process and interact with the world [7]. To avoid beginning with such an impoverished set of humanist assumptions, form and movement (and learning, as we will see later) need to be developed in concert. Our performative process attempts to resolve the 'chicken-and-egg' problem of not pre-defining the robot's form, while still having 'something' to move and learn from.

To iteratively 'find' and refine the robot's form, PBM involves a machine 'costume' or 'prosthesis', which is inhabited and activated by a dancer. It is a wearable object, which extends the dancer's body and stands in for a potential machine body, that is, the machine to be 'bodied'. The shape of the costume/prosthesis is not fixed but is changed and evolved in response to what kind of movements and bodily relations the dancer can activate. It allows (1) for the dancer to 'feel into' the machine's form, and learn to embody and move with this unfamiliar 'body', and (2) for the robot to learn from the dancer by imitating the recorded movements from the dancer, disguised to mirror the robot's embodiment.

From a technical viewpoint, the costume is a full-size, non-mechanical prototype of a robot design in process. Involving the bodily imagination [8] and kinesthetic empathy [9] of a choreographer and a dancer, however, it becomes an instrument for mapping between two very different embodiments, and for the dancer to embody and skilfully tune into this strange object to explore how it becomes-body in movement. The dancer's movements, in turn, are co-shaped by the material forces and affordances of the machine costume, so that their distinct movement qualities emerge from a material interdependence between the two. The use of costumes to co-shape dancers' movements is not new. Oskar Schlemmer designed geometric costumes for his dramaturgical concept for *Bauhaustänze* [10]. Heiner Müller asked Yohji Yamamoto to design costumes for the singers in his 1993 production of *Tristan and Isolde*, "that would impede on the movement they are used to" [11]. In PBM, we are seeking a productive entanglement of the material potentials of dancer and object, rather than impeding the dancer's movement.

2.2 Materials, Forms and Forces

In the first series of workshops, the focus was on challenging assumptions and preconceptions with regards to possible machinic forms and movements. We currently don't have a specific social task in mind, which the robot should fulfil, given that any known social roles already bring with them a set of 'do's and don'ts'. Rather, we explore how far we can push the relationship between abstract, simple morphologies and their potential to elicit connection-making and affective responses. Particularly in the early stages of our project, this open, exploratory approach allowed us to experiment with a wide range of possible forms, materials, movements, and dramaturgical scenarios without the constraint of the robot design needing to fulfil a specific purpose.

To activate the machine costumes/prostheses, we collaborate with dancers from the De Quincey Co. and its artistic director and choreographer Tess de Quincey. The De Quincey Co. [12] trains in BodyWeather, a practice founded on Butoh dance, which draws from both Eastern and Western dance, sports training, martial arts and theatre practices. BodyWeather practitioners are well attuned to the challenging task of bodily thinking through 'other' body-forms. In Tess de Quincey's words, "the whole point about BodyWeather is to go beyond the biomechanics through images, [that is] we recruit the biomechanics to find ways to move, which are not normally positioned as human movements" [13].

Figure 1: *Soft, textile costume, inhabited by Tess De Quincey*

At the start of the project we asked the dancers to inhabit a wide range of materials, shapes and objects to narrow the scope of possible paths. This included filtering out materials and forms that, when activated, either relied too much on the dancer's own morphology or whose structure and movements were so complex that they were likely to be perceived as a spectacle. It is worth noting that we are not aiming to create a machine spectacle, where how the machine looks like or what it can do grabs people's attention. Similar to the issue of giving lifelike characteristics to the robot, this would distract from our aim to better understand how movement can produce and activate connections and sensations that visual appearance alone cannot (we will reflect more on the affective and empathic dimensions this involves in Section 3). Hence, our objective is to foreground movement and how it 'bodies' [6], while avoiding the temptation to make analogies to known or living 'things'. Our starting criteria for 'finding' non-organic morphologies included simple abstract forms, without a front or back, head or face, or limb-like structures, similar to a blank canvas. Another important enabling constraint for the costume was that it can be reconstructed as a mechanical prototype capable of moving on its own and able to imitate the dancers' movements (see Section 2.4).

In the first workshops we experimented with soft, textile structures, inhabited by a dancer, and surfaces with fiberglass ribs that form architectural, parabolic shapes when bent, twisted and pulled by the dancers. The relatively soft shapes, as shown in Fig. 1, however, were too reliant on the dancer to give them a contour. The architecture-inspired, textile shapes, supported by elastic rips, produced interesting evolutions of geometric volumes but didn't allow for smaller, subtler movements.

In following workshops we experimented with simple geometric forms and material structures that could be transformed through the dancer's movements. It quickly became clear that the simpler the form, the more our focus shifted towards the dancer's transformations and their meaning-making potential, without being distracted by many potentially moving parts. In the following, we briefly explore three of the most interesting objects and how they were transformed.

2.2.1 Spiral Tube. The first object that we worked with in this series of workshops was a 190cm-high, 50cm diameter spiral tube, coated with a strong nylon textile, which acted like a relatively stiff spring, standing upright on its own but compressible to a height of only 30cm. First the dancer explored the object's materiality, seeing, probing and feeling what it can do and learning to negotiate its structural integrity. This included learning to move *with* the force provided by the structure, rather than moving the structure. Soon the dancer (inside) began to improvise with the object, exploring different movement shapes and playing with tension, based on the feedback she received from the choreographer and the object itself. The helical structure, shown in Fig. 2, allowed for simultaneous contractions and expansions along the vertical axis of the object, as well as being bent as to produce multiple differently articulated planes pivoted along its core. Both, flexible and responsive, the structure enabled the dancers to generate subtle movements, like a teeter or twitch, which, together with more sustained movement trajectories, produced a rich, expressive performance.

Figure 2: *Spiral tube costume, inhabited by Kirsten Packham, showing multiple articulated planes pivoted along its core*

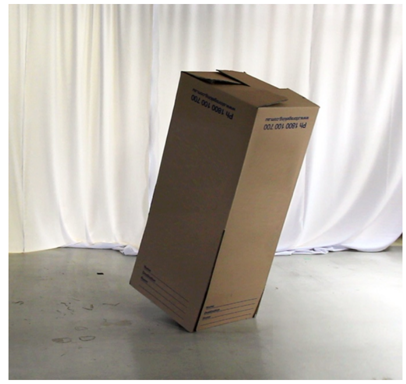

Figure 3: *Box costume, inhabited by Linda Luke, tilted onto one edge*

2.2.2 Cardboard Box. This experiment involved the perhaps most obvious simple, abstract form, yet not the most apparent in terms of its evocative capacity—a box. At first we asked the dancers to inhabit a 150x55x45cm cardboard box, as shown in Fig. 3. The stiff box shape got immediately interesting when it balanced precariously on an edge or was tipped onto one corner by the dancer inside. Confronting our notions of weight and gravity through tilting, swaying and teetering allowed for the box to lose its stability and, with it, its 'boxiness'. This transformation or making strange and how it can open-up an object for becoming-body, taking on its own presence and actively relating to its environment is at the very core of our methodology. In later sessions, we challenged the 'boxiness' of cube-proportioned cardboard boxes, experimented with different scales and added concertinaed openings (see Section 2.3).

Figure 4: *Tehtrahedron prosthesis, built with PVC pipes, tightly strung together*

2.2.3 (Broken) Tetrahedron. As shown in Fig. 4, the regular tetrahedron has a 1m triangular base and 2m long upright edges. We wanted to bring back the elastic forces, which the dancers could play with inside the spiral tube, and built the pyramid shape with PVC pipes, tightly strung together with elastic rope. Using pipes compressed through elastic rope allows for the shape to arise from a continuous network of tension. Importantly for us, this elastic tension allows for the structure to maintain its shape but also for the edges to be twisted and the vertices—being joints—to have some play. Initially we had planned to coat the structure to produce a closed object, which the dancers could inhabit, however in our first experiment one connection along one of the up-right edges broke. Now the tetrahedron had a fifth joint (Fig. 5). Rather than repairing the fault, we were fascinated to find the multitude of shapes we could produce by moving the new joint of the broken edge. While this unexpected, emergent complexity counters our aim to focus on very simple forms, the simplicity of the kinetics that produces these transformations opens up a new pathway for our study. The following section explores the potential that this serendipitous event opened-up for the becoming-body of this object.

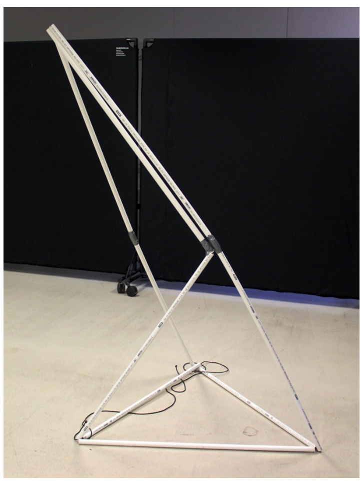

Figure 5: *Tehtrahedron prosthesis with one broken joint*

2.3 Becoming-Body

As stated earlier, the form of the costume/prosthesis is not fixed but only provides a starting point for the iterative design and becoming-body process. Once initial studies, such as those discussed in Section 2.2, produce interesting or unexpected results, the object is opened up, in a way, to be expanded and refined. This process is informed by our material observations, in-depth conversations with the choreographer and dancers, and reflections on our decisions as well as serendipitous events. The latter, e.g., the breaking of a component, which opens-up another degree of freedom, or a material behaving in unanticipated ways, played an important role in 'finding' and refining the robot's form. Interestingly, the decisions we make usually draw some sort of line, a boundary, which sets the direction forward but also cuts off other potential pathways. Serendipitous accidents, we found, work more like a small explosion, a sudden release from set ideas and made assumptions, opening up new, previously unseen pathways.

In this section we take a closer look at two modified costumes/prostheses, and at the dancers' process of bodily negotiating their materiality and the emerging transformation. It is the process of the object becoming more than an object, that is, of it becoming an interesting, affective body by moving, relating to the environment, and taking on a presence of its own.

We found that the costume/prosthesis becomes a body as soon as the dancer enters it and begins to negotiate its material tensions and forces and to 'find' movements *with* them. In one session, for instance, Tess de Quincey asked the dancer, inhabiting the cardboard box, to express a question mark. When the dancer responded to the prompt, we witnessed the box performing a shape, seemingly positing layers of hesitation, inquiry and alertness along its movement trajectory. Rather than a positing, to be precise, we experienced the *finding* of a movement, starting off with a hesitating twist that accelerated upwards with a slight inclination, before it came to a sudden halt. This was not a visual representation of a question mark, but rather the bodily processing of what a question mark *does*. The box-becoming-body emerged from the "movement subtleties and qualities, contrasts between tension and relaxation, and between high degrees of physicality and absolute stillness" [14].

2.3.1 Cardboard Box with Concertinaed Openings. The simple cardboard box promised to have an interesting bodying potential, precisely because it was such a familiar, unassuming object, which made witnessing it become more than a box all the more surprising. This was confirmed when we expanded the box shape with concertinaed openings, as shown in Fig. 6. The idea was to see if the expressivity of this simple object increased when we allowed the shape to open up. To test this, we worked with a costume designer to open up the cube's four side faces and to reconnect them via concertinaed paper membranes, spanned between the now door-like open faces and the remaining cube 'body'. Once inhabited and activated, however, we found that this capacity to open-up, reconfigure and unfold the box made it much harder to comprehend and relate to the box's movements, in particular as it seemed to overshadow any softer or fragile movement textures and rhythms that the dancer produced.

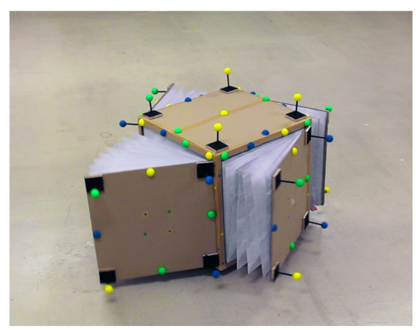

Figure 6: *Cardboard cube costume with concertinaed membranes (inhabited by Kirsten Packham)*

There was an unexpected side effect, however, when the dancer moved the box without actively pushing-out or pulling-in the membranes. Then, any small slip or twist, sudden slide or tilt would make the side faces quiver and wobble, as if each movement created a wake (Fig. 7). This 'secondary motion', as it is referred to in animation [15], extended the dancer's movements, similarly to the springy effects we saw in the spiral tube or the elastic tetrahedron. What is so interesting to us about this extra motion or tension, is that it not only extends the object's movements but also performatively expands the material negotiation between dancer and object. After all, as we discuss further in Section 3, the aim is for the dancer not to control or puppeteer the movement of the object but rather to develop movement *with* it, involved in a material feedback loop.

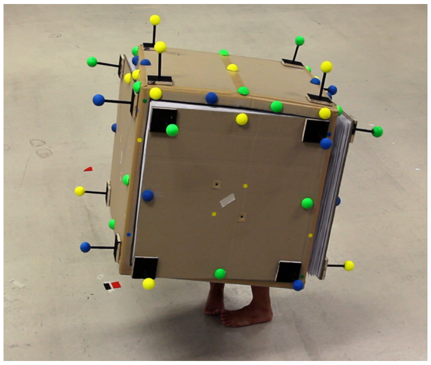

Figure 7: *Cardboard cube costume (inhabited by Kirsten Packham), playing with membranes' secondary motion*

2.3.2 Broken Tetrahedron. The dancers often talked about this particular form as an extension of their body. Building the form out of PVC pipes without giving it a surface meant that the dancers could choose to work with it like a prosthesis, rather than a costume. The lightweight, open structure allowed them to easily move between inside and outside, and thus also to approach and think through the object from these different positions. Interestingly, as they changed the location of their focus, they also used different techniques to move with the form (find more details in Section 3). As mentioned above (Section 2.2.3), the slightly broken tetrahedron proofed a more interesting becoming-body than the initially conceived, unbroken one. As a result of the broken joint, the object does not only move and twist as much as the underlying elastic network permits but also reconfigures into a number of shapes. Thanks to this continuous tension, holding the structure together, as shown in Fig. 8, these transformations require only the moving of one joint, either at the bottom of the broken edge or the broken joint itself. Fig. 9-10 show more of the distinctly different shapes (or bodies) that moving the single joint can produce. In later sessions, we introduced broken joints in all three legs, so that the structure no longer had a unique side or 'face' to it. Unsurprisingly, tripling the number of joints also multiplied the potential of movements and shapes that the dancers can create, and, with it, the time it will take to train the machine learner (Section 2.4).

It is important to note that this structure's transformability alone is not rendering the object a more interesting potential body. On the contrary, simply reconfiguring the structure produces intellectually interesting and/or dynamic shapes, but we found that this built-in 'cleverness' doesn't lend itself to becoming an affective body. The first engages us because we want to understand what it does and how it does it, while the latter engages us in the form of sensations, prior to formulating these questions. Sensations constitute, in Elizabeth Grosz's words, a "zone of indeterminacy between subject and object, the bloc that erupts from the encounter of the one with the other" [16]. We are drawn in because of the way it moves, sustains a tension, gently spaces a path or suddenly halts, etc., rather than the shapes we can recognise (or not). Hence its presence emerges from its movement, that is, the differences in energy and texture and how variations of tension and speed produce unpredictable yet readable spacings and spatial relations. Erin Manning states that "[w]hat dance gives us are techniques for distilling from the weave of total movement a quality that composes a bodying in motion" [17]. It is fair to say then that the structure's transformability offered a multitude of starting points for the dancers to play and 'body', and for the form to become more than object and to take on different identities.

Figure 8: *Broken tetrahedron prosthesis, inhabited by Tess De Quincey, moving only one joint*

2.3.3 Motion Tracking. The motion of the activated costume/prosthesis is tracked to (1) inform the model for a mechanical prototype that resembles the costume/prosthesis and its capacities to move as closely as possible, and (2) provide data for the machine to learn from (see more details in Section 2.4). This is the stage, where the movement emerging from the costume–dancer entanglement becomes the diagram for the robotic mechanism and, with it, its ability to learn to move based on its unique machinic embodiment.

2.3.3.1 Tracking the Cube. We recorded the cube's movements using a video-based motion tracking system by attaching coloured targets to the cube's surface, as can be seen in Fig. 6-7. Activated by a dancer inside, the cube was recorded using two HD cameras arranged to ensure that all sides of the cube, except the base, were captured. The video recordings were analysed using motion tracking software and the resulting tracked 3D points were used to animate a model of the cube using Maya and custom scripts, which was then exported as a CSV file with the x, y, z position and the yaw, pitch, roll angles of the cube, together with the angle of each side face, when pushed open. Each of these samples becomes an input variable (in the form of a vector) to the machine learning system, whose task will be to learn how these vectors change over time.

2.3.3.2 Tracking the Tetrahedron. The movements of the (broken) tetrahedron were recorded by augmenting the construction with instruments to measure the angle that the broken leg of the tetrahedron makes with the floor. This was achieved by using two Dynamixel MX-64T servomotors, arranged as a pan-tilt unit; by relaxing the motors they provided two angles that describe the orientation of the broken leg to the floor. Given the orientation of the edge (leg), we can then determine the position of the 'knee' of the broken leg. The geometric and physical constraints on the tetrahedron are such that a 3D simulation of the complete system can be reconstructed. This simulation is then used to determine the positions of any motors needed to replicate the recorded movements, e.g., pan and tilt units for all three legs. Like above, these tracked angles will serve as an input variable (in the form of a vector) to the machine learning system.

2.4 Learning to Move Based on the Robot's Unique Embodiment

Recognising and tapping into the difference of the machine's embodiment and how it can elicit new relations is at the very core of our project. Hence, rather than looking at the robot's body as a mobile container, we have developed our machine learning approach in tandem with the robot's embodiment and capacity to move. To explore this interdependency in more detail, the following outlines the first three machine learning phases, *grounding*, *imitation* and *improvisation.* Later learning phases will engage choreographers and dancers to develop performance scenarios for the machine to learn and improvise in more complex sociomaterial environments beyond the lab.

2.4.1 Grounding. In the *grounding* phase, the robot learns how it can move in relation to its environment through trial-and-error to ground its movements and relations and any future learning in its own specific embodiment [18]. This approach contrasts with common approaches in social robotics, in which the robot's control system and its body are still considered separate, so that the artificial nervous system operates "largely independent of the body it is carried out in" [19]. We deploy the developmental robotics [20] method of 'motor babbling' [21], which allows for the robot to 'discover' its own body and possible kinesthetic relations in response to environmental affordances. Through this active self-exploration, the robot gradually generates a body map, which is unique to its own material body and intricately couples it with the control system, developed in response to the body's capacity to move. This body map will allow the robot to learn and improvise movements later on, without requiring them to be programmed 'into it'.

2.4.2 Imitation. In the *imitation* phase, the robot learns to imitate the movements of its dancer-activated costume twin, as closely as its own body map allows. Imitation learning is the most common type of social learning in Human-Robot Interaction (HRI) and is generally used to teach robots humanlike skills and behaviours. The challenge of this embodied form of learning arises from having to map/translate between the two very different embodiments of human and machine, which results in a machine-learning problem, the well-known correspondence problem [22]. Our Performative Body Mapping method offloads the morphological mapping onto the dancer, as she learns to move with the costume/prosthesis, avoiding the need for complex data-mapping between radically different bodies. Rather, the tracked data from the costumes/prostheses essentially allows the robot to learn from movement data of its own mirror image. As it learns to imitate the costume's movements, the goal is for the robot to learn the constraints that produce the movement qualities and subtleties, which emerged from the dancer-costume enmeshment. Hence, rather than only learning a specific set of movements, the robot gradually learns patterns of movement, that is, "the systematic way patterns are structured, sequenced, and related to one another" [14], based on its own machinic body sense (see Section 2.4.1).

2.4.3 Improvisation. Finally, in the *improvisation* phase, the robot learns to adapt its previously learned patterns of movement to invent new movements, with feedback from the choreographer. Drawing on methods from computational creativity [23], the machine learns to play with the movement material given to develop movements that are unique to its own machinic body and its relations to the environment.

3 DISCUSSION

In contrast to primarily software-based AI applications, robots have a body through which they perceive, interact with and reconfigure the world, enabling them to share our social spaces in embodied ways. We believe that our experience of such a shared embodiment and its social potential is firmly rooted in our experience of movement. Movement here is not "a change of position" [24] or a recognizable, socially coded gesture but rather understood in terms of its specific articulated kinetic dynamics, its ability to shape and reconfigure space and mobilise affect. In this section, we will discuss our Performative Body Mapping (PBM) methodology from the dancers' point of departure and the kinesthetic experience of non-experts. The first looks at some of the techniques and concepts the choreographer and dancers used to 'body' the robot, and the latter (briefly) touches on our inherent kinesthetic abilities to form connections and to access other bodies, human and nonhuman.

3.1 The Dancers' Kinesthetic Experience

Dance is created from specific "integral kinaesthetic structures" [24], similar to everyday patterns of movement, such as brushing one's teeth, signing one's name, etc. Yet in contrast to these familiar movement patterns, according to Maxine Sheets-Johnstone, dance's "corporeally resonant dynamic patterns" are initiated, unfold and "flow forth" in distinctly different ways: their kinetic dynamics are carefully attended to and "fully and finely experienced" [24]. In addition to dancers' skilful attendance to the becoming of movement, some choreographic practices also aim to articulate concepts of what constitutes a body and how it relates to other bodies and the environment in ways that significantly expand our common understanding of bodies and its surrounds.

For BodyWeather practitioners, the human body extends beyond its anthropocentric bounds and the binary notions of self and other. They often use mental images for the body to work from, in order to, in choreographer De Quincey's words, "shift it out of its known, habitual pathways" [13]. The images assist them to reconfigure their bodies through either imagined external forces, i.e., wind or pressure, or reimagining their own body, i.e., as a distributed nervous network ("nervous body" [25]). This allows the dancers to escape the habitual and 'find' new kinetic patterns to bodily explore the spacings and tensions that these images evoke. For choreographer Deborah Hay, the body is "a site of exploration" [26], playfully reconfiguring itself. Using images, she reimagines the body as a continuously changing, dynamic "performance of seventy-five trillion semi-independent cells" [26]. Importantly, the images aren't there to be expressed by the movement patterns, but rather to be engaged in a dialogue with, bodily.

Figure 9: *Broken tetrahedron prosthesis, inhabited by Tess De Quincey*

This kinesthetic dialogue and how it can shape a body and our experience of movement also is at the core of PBM. In essence, PBM, with its abstract, non-anthropomorphic robot costume/prosthesis, introduces an additional source for inspiration and a specific set of material forces to explore and 'find' movements with. The unique kinetic experience that is produced from this material entanglement then becomes as unique set of constraints for the robot to learn from.

Rather than moving the costume/prosthesis, dancers quickly learned to move *with* the strange morphology, and the inherent material potentials it afforded. The material entanglement and process of bodying extended beyond the physical confines of the costume/prosthesis, as the dancer's bodily negotiations were often co-shaped by a dialogue between herself and the choreographer. The latter developed her ideas from outside, looking onto the costume-becoming-body, while the dancer responded from within and the material experience, which only she had access to.

With the 'broken tetrahedron' and its open pipe structure, we introduced a new variant of the PBM method, which allowed the dancers to move between inside and outside. They could choose to inhabit the structure or position themselves outside to reconfigure the structure. It was interesting to witness how this difference in positioning themselves also changed the location of their focus and made them use different techniques and imagery to move with the form. While the dancers are able to extend their bodies (and images) to the structure, even when positioned outside the object (Fig. 10), their bodies clearly get more entangled with the material structure when inhabiting the structure, as shown in Fig. 8-9. According to the dancers, when positioned outside, they relied more on their visual sense to initiate and explore movement patterns, which made them vulnerable to attempting to control the structure's movement [27]. Whereas from inside the structure, they used their body configurations with their different intensities to feel into, reshape and move with the structure [27]. This observation affirmed two core assumptions, which our PBM approach builds on: (1) the significance of a physical robot costume/prosthesis, which can be bodily thought *with*, and (2) the potential of this costume/prosthesis to be bodily inhabited and thus bodily negotiated from within. This bodily thinking with external forces and other bodies is, we believe, a powerful example of kinesthetic empathy.

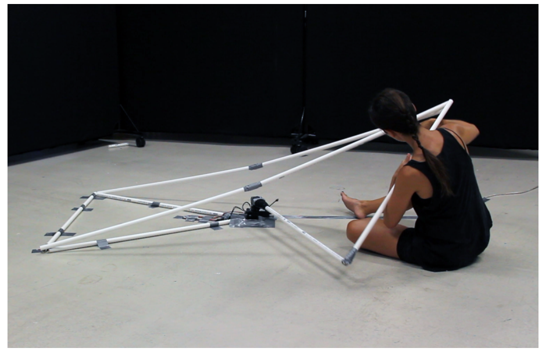

Figure 10: *Broken tetrahedron prosthesis, reconfigured by Kirsten Packham*

3.2 Kinesthetic Empathy

The success of our kinesthetic approach will not only rely on the dancers' empathic experience with these strange, other bodies but also the empathic response of non-expert audiences. As we have not yet reached the project stage, in which we study audiences' experience of our robots, this section briefly outlines some of the theoretical concepts, which co-shaped our approach.

The concept of kinesthetic empathy, as we refer to it, is concerned with the body's sensitivity to and connectedness with other bodies and its environment. According to Sheets-Johnstone, "[w]e literally discover ourselves in movement" [28], and we make sense of the world and other bodies based on our kinesthetic understanding and sensibilities. The empathic potential of kinesthetic experience [24, 29] is at the heart of our PBM approach as it aims to unlock the connection-making capacity of abstract, non-anthropomorphic machines; in other words, bodies whose becoming does not rely on human- or animal-like qualities.

There is much research on a moving body's capacity to resonate with the observer [30, 31, 14], arguing that observed movement literally moves and bodily affects us [30]. While we believe it is problematic to limit the experiencing body to the external position of observer, this argument is nevertheless very interesting in relation to human-machine configurations. The interdisciplinary concept of kinesthetic empathy explores the affective potential of movement, and, with it, our innate capacity to kinesthetically experience other bodies. It is "a movement across and between bodies, which … can have affective impact with potential to change modes of perception and ways of knowing" [9]. This powerful relational capacity has also been explored in interactions with objects and environments [32, 9]. Empathy with nonhuman 'things' is aligned with anthropologist Alfred Gell's view that "it does not matter, in ascribing 'social agent' status, what a thing (or a person) 'is' in itself; what matters is where it stands in a network of social relations" [33]. This suggests that social capacity is not restricted to familiar physical attributes, but arises from a body's capacity to relate to its social environment.

4 PRELIMINARY CONCLUSIONS

This is an ongoing research project, and the next stage will involve implementing the machine learning and autonomously moving mechanical prototypes and to evaluate their kinesthetic performance in public settings involving non-expert audiences. The workshops to date have explored bodying of potential robotic forms through an iterative process of prototype construction and embodied explorations of the kinesthetic potential of machine costumes/prostheses by choreographers and dancers.

The exploratory nature of the bodying workshops, a core component of our PBM method, has permitted the discovery of unanticipated aspects that will drive the design of our prototype robots and their movement potential. The serendipitous discovery of the surprisingly affective potential of a tetrahedron with a single broken leg has opened up new design possibilities for simpler robotic prototypes. The ability of secondary motion to amplify the subtle movements of dancers will be explored in the design of machine learning systems to determine if grounded robot control systems are able to exploit secondary motion, not under direct motor control, to increase the affective potential.

The results of the workshops supported our original idea that the robot design process can be effectively opened up to movement experts in ways that allow them to bodily engage with possible robotic forms and explore their kinesthetic potential. Exploiting the tacit knowledge of movement experts, the design process transcends the production of geometric or life-like forms to become a process of bodying that is grounded in kinesthetic experience.

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