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Intra-Acting Body and Textile Expressions Becoming with Digital Movement Translation

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Exploring relational expressions of the body and textiles using a human-robot-textile installation

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Body-centric design disciplines that utilize digitization processes such as fashion are tasked to engage with theoretical concepts commonly applied in digital-native design disciplines in order to use digital technologies as more than simple tools. Guided by intra-action theory, alternative ontological and hierarchical relations between the body and textiles were explored by digitally translating their movement. An installation was developed to find hybrid body-textile expressions using motion-capture sensors and robotic arms. The findings suggest that technological augmentations of the body and textiles can increasingly be diffracted in terms of their apparent physical-material boundaries through movement translation. Movement data functioned as a performative mediator, expanding movement-based expressions from one agent to another. Body-textile hybrids emerged from this process, and shaped each other in a mutual act of becoming, challenging ontological structures of the body and textiles commonly applied in fashion design.

CCS CONCEPTS • Human-centered computing • Human computer interaction (HCI) • Interactive systems and tools

Additional Keywords and Phrases: Textile-robot interaction, Responsive textile systems, Hybrid bodies, Movement as material

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1 Introduction

The digitization of fashion design processes in academia and the industry is undertaken in order to improve garment production processes in terms of sustainability and finances [43, 54, 71], yet very few studies have explored alternative functional and expressive qualities of digital body-dress relations [35, 55]. While three-dimensional computer-aided design (CAD) software such as CLO3D and Browzwear reduces the need for physical prototyping of garments [57], suggests the potential of zero-waste design thinking in garment production [42], and improves the communication of design ideas among both students and industry professionals [49], such tools are designed based on an established dichotomy between body and dress that considers them to be separate entities in order to replicate physically based garment-construction processes [3, 55]. Recent efforts by digital-only fashion companies and collaborations between fashion brands and digital game-development studios have resulted in digital and hybrid fashion experiences that have offered little difference compared to their physical-only counterparts [65].

Fashion design as a discipline that seeks to develop meaningful and alternative experiences with digital technology will require a conceptual understanding of digital technology in its mediating role that goes beyond seeing it as a tool [64, 65]. As such, it may prove useful to engage with the theoretical concepts that have been increasingly applied in digital-native design disciplines, rather than primarily defining the role and potential of digital technology based on theory that is specific to the physically based history of fashion [55, 65]. Approaching ontological questions of when something is, or is becoming a body, a garment, or a textile [67], through a theoretical lens that has been acknowledged by communities within HCI may contribute to expanding knowledge in fashion. Doing so could show awareness of the constituting influence digital technology can have on what we define as fashion experiences and how we engage with and design these.

The research presented in this article contributes to this discourse by exploring the ontological dynamics of digitally constituted bodies and textiles through the lens of intra-action, using agential realism as its underlying theory [5, 6]. As such, the body and textiles are explored as part of a process of relational becoming [through entanglement], rather than in relation to a merging of forms that existed prior to their entanglement. A textile-robot installation was developed to artistically explore the relational becoming of the body and textiles that sense and act on each other through movement translation. Digitally mediated movement was considered to be the phenomenon that connected the body-textile configurations, which disrupted common concepts of the body and textiles in fashion.

The findings suggest that digital processes for translating and processing phenomena such as movement can create hybrid body-textile configurations wherein the body and textiles cannot be separated from each other based on their physical-material boundaries and affordances. Instead, they expand toward each other through movement translation. These findings contribute to an increasingly digital design discipline by suggesting a conceptual openness toward relational expressions and affordances of the body and textiles in relation to digital technology. Beyond fashion design, the findings contribute to a growing discourse on the use of intra-action theory through the exploration of body- and textile-related expressions in relation to robotic movements.

2 Background

The research presented in this article is transdisciplinary at its core, as it is based on fashion design, interaction design, and digital computing research. Previous work undertaken in these disciplines was used to guide the explorations and situate the findings within the context.

2.1 Agential realism

Agential realism theory, as proposed by Karen Barad, advocates “a relationality between specific material (re)configurations of the world through which boundaries, properties, and meanings are differentially enacted” that “refuses the representationalist fixation on words and things and the problematic of the nature of their relationship” [5, p. 138]. Data, expressions, and things cannot be seen as representations of an external world that exists independently of activities such as measuring, observing, and interacting; rather, it is through the entanglement of subject and object, the instrument and the observed or measured, that the two engage in a process of mutual becoming. Consequently, agential realism shifts the focus from the things and objects of design to how design materials, people, and the environment interact with each other [5]. In other words, agential realism considers phenomena to be the basic ontological unit, rather than things.

Intra-action, as a conceptual lens which has agential realism as its underlying theory, emphasizes the interconnectedness that is crucial to this theory while paying close attention to materiality [5, 6]. As such, intra-action leads to a shift in focus, away from the attributes of an individual subject or object and toward performances or phenomena as ongoing and emergent. Revealing the intra-actions of entities requires a distinction to be made between the apparatus and the world, the subject and the object, based on the phenomena one intends to measure. Barad calls this active choice an ‘agential cut’, which makes causes (measured objects) and effects (measuring subjects) within phenomena possible to separate [5, p.148].

Barad refers to revealing intra-actions between entities through agential cuts as engaging and attending to difference, rather than expecting entities to reflect reality in a straightforward way that constitutes their existence prior to their entanglement [5]. It is through ‘diffraction’, which Barad defines as a metaphor for inquiry focused on attending to difference, that we can attend and respond to the relations of difference as a kind of interference [5,

p. 7]. This in turn is a specific material entanglement that reveals details and specifics and provides understanding regarding their becomings and how they matter.

Examples of engaging with agential realism theory within HCI have ranged from attending to the materiality of data during the design process rather than treating it as an insight-laden thing [40, 41, 53], to making visible alternative discursive-material configurations of problems to suggest different ways of seeing and describing the world [26], challenging the notion of learning through diffractive data analysis of an online-learning platform [48], and exploring soma design as performative intra-actions [60].

The research presented in this article explores concepts of the body and textiles, as defined in fashion design, through the lenses of intra-action and diffraction. Rather than seeing the body and textiles as entities with pre-existing conditions, they were explored as entangled becomings that emerge through apparatuses, technologies of observation, in the form of the ‘agential cut’. This allows the ‘matter’ of the body and textiles to be explored as entangled ‘doings’ rather than pre-defined ‘things’ [7, 10].

2.2 The body and textiles in fashion

The human body and dress, as an expression of textiles, are commonly perceived simultaneously during the moment of wearing; dress covers the body and makes it socially acceptable through conformity [17], alternates sensory perception through haptic and tactile stimuli [50], and influences bodily posture and movement [67]. Yet, both the human body and textiles remain distant from each other in industrial design processes for dress, and this is further amplified by the increasing use of digital technology [55, 65]. Hence, conceptual understandings of the human body in fashion (as something to design for) and textiles (as something to design with) have influenced how digital technology has been designed for fashion, and contributed to an established dichotomy between the body and textiles as separate entities in the digital design process, rooted in the physically based history of fashion [3, 34]. Consequently, digital technology has been primarily regarded as a tool for designing garments in fashion education programs and the industry, rather than as a mediator or agent through which alternative relations between the body and textiles can be explored [55, 65].

Research examples that have explored the affordances of technology in fashion beyond considering them simply to be tools for garment construction have engaged with motion-capture (MoCap) technology to explore digitized textile movement [11, 58, 59], inverted movement-based hierarchical relations between the physical human body and textiles by moving a digital human body using physical textile movement [66], and explored the disruptive potential of three-dimensional scanning technology with regard to deconstructing human bodies through movement [64].

Research at the intersection of textile design, interaction design, and architecture has developed technologically augmented textiles capable of movement interaction [12, 13], explored the aesthetic implications of temporal textile expressions through self-initiated textile movements [16, 45, 51], raised questions of agency concerning textiles as sensing and self-acting bodies [52], and investigated applied scenarios relating to increasing body-awareness [14, 68].

2.3 Robotic systems

Interactions between robotic systems and human and non-human agents have been widely investigated in architecture, design, HCI, media, and the performing arts, with a variety of focuses: the perception of robotic arms as part of one's body [4], overcoming anthropomorphism through robot-specificity in motion [1], and intra-action-based performative-relational models of human-machine communication [23]. An outstanding example of robotic-textile motion in art is *Black Flags*, wherein “waving flags translate the digital algorithm that controls the robots into a series of gestural movements in space” [19]. In the field of human-robot interaction, *Mimus* explores a robotic motion language native to individual robotic bodies in relation to motion-tracking data [22]. *Double-Taker (Snout)* investigates subjecthood and gestural interactions based on real-time machine vision [32]. In contrast, *Doing Nothing with AI* used online machine learning to explore the emergence of dialogue-like interactions between human and robotic bodies [24].

The use of industrial robots can be divided into three main categories: the first approach is the most common way of integrating robots in industrial and creative processes, wherein tasks for the robot are designed in a simulation then deployed using a robot controller. The second approach involves piloting the robot via a physical or visual interface. The third approach utilizes software, also known as a robotic system, to enable real-time

transmission of a stream of data, parse this data into meaningful information, and process an output with respect to the environment and external entities that the robot is interacting with. This third category of real-time interaction can be further sub-categorized based on utilization of Behavior Trees [30] and State Machines [31].

The combination of the Grasshopper software package for Rhino and the KUKA|prc plugin is one way of designing robotic motions in a visual programming language [8], primarily utilized in the fields of architecture and design, along with diverse other domains. Because Grasshopper does not have the capacity to define state-machine interactions, efforts have recently been made to define interactive robotic processes using Unity Visual Script [9] and the visual live-programming environment vvvv. The toolkit developed for vvvv, also known as the ‘bunraku project’, facilitates the translation and communication of any stream of data to one or more KUKA robot controllers in real-time [44].

With regard to moving industrial robotic arms in real-time, robot manufacturers and open-source communities have created interfaces to achieve this. mxAutomation [46], Robot Sensor Interface (RSI) and KukavarProxy [2] have been developed for use with KUKA robots; in contrast to the others, RSI allows the definition of a custom data flow every 4 ms, and thus enables the creation of custom data-handling and motion-calculation processes. This provides the possibility to set maximum acceleration rates and maximum velocities per axis, as well as customized interpolation and responses to incoming data.

2.4 Movement in HCI

The relationship between the human body and technology has changed substantially due to rapid technological advances over time [70, 27, 36]. As such, several researchers have identified the importance of a deeper and more exhaustive analysis of the human body in order for HCI to suggest improved approaches to designing with and for interactive technology [70, 39]. When working with such a perspective, the moving body is an essential element of interactions between humans and technology, and its complexity is manifested through different research approaches, questions, and understandings regarding its use and consequences for HCI [36].

Phenomenological and post-phenomenological perspectives have informed a substantial quantity of research into embodied actions and their usage in interaction design [33, 61, 15, 62, 18, 39]. The qualitative study of embodiment and the use of first-person perspective establish an experiencing and perceiving being a body from within, and this approach has been explored by multiple researchers interested in collaborating with dancers and somatic practitioners [33, 29, 39, 69, 38]. The inclusion of somatics in HCI is emphasized in soma design, wherein technological and digital materials merge with the designer’s and user’s soma in order to holistically approach design aesthetics [28, 56]. Numerous designers have incorporated this concept, proposing interpretations and design solutions that have expanded knowledge of how movement and the experienced body can be interpreted and analyzed during interactions with technologies. Several of these investigations have examined movement as a design material [25], exploring dance improvisation as part of a movement-sound programming tool [20], motion to understand kinesthetic creativity in dance [29], the designer’s body as a resource [62, 63], and soma design [60, 37].

Using post-humanism and relational ontologies, Frauenberger expanded research into moving bodies in HCI by introducing Entanglement HCI [21]. This proposes an alternative understanding of the body where it is defined by entanglements between humans and computers. Following this theoretical framework may trigger the development of methods, concepts, and techniques for the design of HCI that acknowledge bodies and technology to be equally constitutive entities. Such a post-humanistic approach manifests in works that explore the creative capacity of the non-human, and the repercussions this could have with regard to the design of future interactive systems [47, 53].

3 Methods

A textile-robot installation was developed, and served as a design tool for exploring alternative ontological and hierarchical relations between the body and textiles, through digital movement translation. The installation consisted of different materials and technologies that connected plain textiles and robotic arms in such a way as to allow them to engage with and respond to each other in real-time.

3.1 Setup

The installation had physical and digital aspects. For the physical setup, three robotic arms produced by KUKA were positioned in close proximity to each other in a confined space (Image 1 of Fig. 1). Each had six axes of movement, but varied in terms of size and range of motion. The largest robotic arm had a range of motion of 2.5

meters in diameter, while the smallest robotic arm had a range of motion of 1.1 meters. The sizes of the textiles that were attached to the robotic arms were determined by the space between the robotic arms and what was being explored. A triangular-shaped textile that measured 7.1 x 3.2 meters was used for Exploration 1. For Exploration 2, six triangular-shaped textiles that had measurements ranging from 7.2 x 1.2 meters to 3.8 x 0.6 meters were used. For Exploration 3, a textile structure consisting of six elongated-diamond-shaped textiles that were sewn together at various points was constructed. These textiles had lengths ranging between 6.7 to 5.3 meters and widths ranging from 0.8 to 0.2 meters.

The digital setup consisted of a desktop computer, the visual live-programming environment vvvv, a KUKA robot controller for each robotic arm, the robotic real-time sensor interface RSI, and the Perception Neuron Pro MoCap system. The MoCap system consisted of 17 wireless MoCap units, an antenna connected to the computer, and the Axis Neuron Studio software. As shown in Images 2 and 3 of [Figure 1](#), the MoCap sensors that were attached to the textiles translated their movement into the digital. Rotation-based values were extracted from the sensors in Axis Neuron Studio and streamed into vvvv (Image 4 of [Figure 1](#)). There, the data was translated according to defined mappings and sent in real-time to the respective robot controllers using the ‘bunraku project’ toolkit (Image 5 of [Figure 1](#)). Focusing on the extraction of rotation-based movement values seemed to provide the greatest degree of coherence, as the parts of the robotic arms move by axis rotation whether commanded to cartesian coordinates or axis position. This approach facilitated a more faithful translation of movement expressions from the textile to the various robotic bodies.

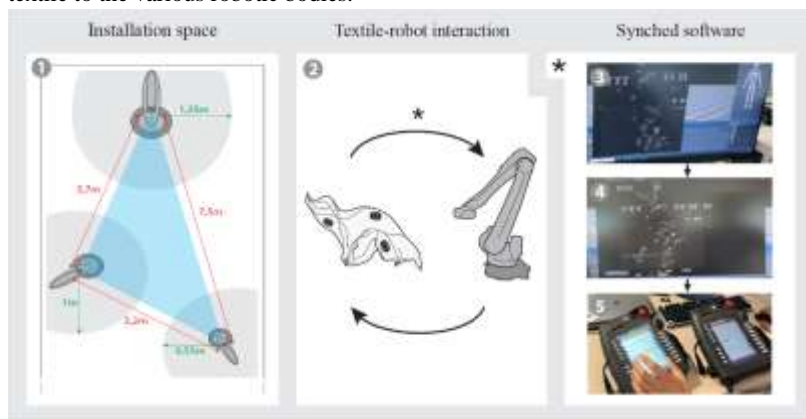


Figure 1: Textiles and robotic arms were connected physically and digitally (Images 1 and 2); MoCap sensors transferred movement data to the Axis Neuron Studio software (Image 3), which provided movement data for vvvv (Image 4), which then streamed commands to the KUKA robot controllers (Image 5).

3.2 Movement-data translation

Connecting the physical and digital aspects of the installation involved understanding how and to what extent the digital movement-translation process, from MoCap to movement-enaction, could influence the emergence of relational body-textile expressions. For this purpose, the kinesthetic robotic-arm system was explored in terms of how the robotic arms moved in comparison to human armature. Based on the observations, five themes consisting of three sensor configurations respectively were developed in order to translate the MoCap data generated by the human-body armature such that it could be performed by the robotic arms, in order to create a movement-sensing and -enacting textile-robot system.

The human-body armature in Axis Neuron Studio was used to make sense of the movement data from the MoCap sensors, which was analyzed for each sensor in relation to the data collected for each sensor connected to it (Image 1 of [Figure 2](#)). For example, when the sensors were used in the default configuration of the humanoid armature, the data collected by the sensor for the right elbow (Sensor 9) was related to that of the sensors for the right hand and shoulder (Sensors 8 and 11). Something similar took place with the robotic arm, which moved each part of itself in relation to the parts it was physically connected to. Despite the similarity in how the movements were tracked and executed – by having parts connected to each other in a specific order – the two systems consisted of different numbers of parts, and how these could move and rotate in relation to each other. The robotic arms

movement was determined by the six parts each consisted of, in contrast to the 17 parts of the humanoid armature. Three robotic arms were used in the installation, meaning that the movement data of 18 robotic arm-related parts was translated using the 17 MoCap sensors (Image 2 of [Figure 2](#)).

Based on the conceptual framework for translating the movement of human-body-based armatures for the robotic arms, five different configuration themes of the MoCap sensors were tried out (Images 3–7 of [Figure 2](#)). For Sensor Configuration Theme 1, the MoCap sensors were connected to one another as they would be on a human body (Image 3); Sensor Configuration Theme 2 was inspired by textile weaving structures, and the sensors were connected in a criss-cross manner (Image 4); Sensor Configuration Theme 3 connected the sensors with each other based on the outline of the armature in different configurations (Image 5); Sensor Configuration Theme 4 connected the sensors with each other in a way to visually outline separate spaces within the armature (Image 6); and Sensor Configuration Theme 5 connected the sensors in the form of abstract humanoid bodies (Image 7). The rationale behind using a variety of MoCap sensor configurations for the installation was to explore the agency that digitized movement expressions possess with regard to emerging relational expressions between the body and textiles. By comparing the movement expressions that emerged across the various sensor configurations, it was possible to see the influence of armature configuration on movement translation, from motion-capturing to motion-enacting, on the emerging relational body-textile expressions. For this purpose, the installation was run with each sensor configuration shown in Images 3-7 of [Figure 2](#) in real-time for 60 seconds with a fluent transitioning between them.

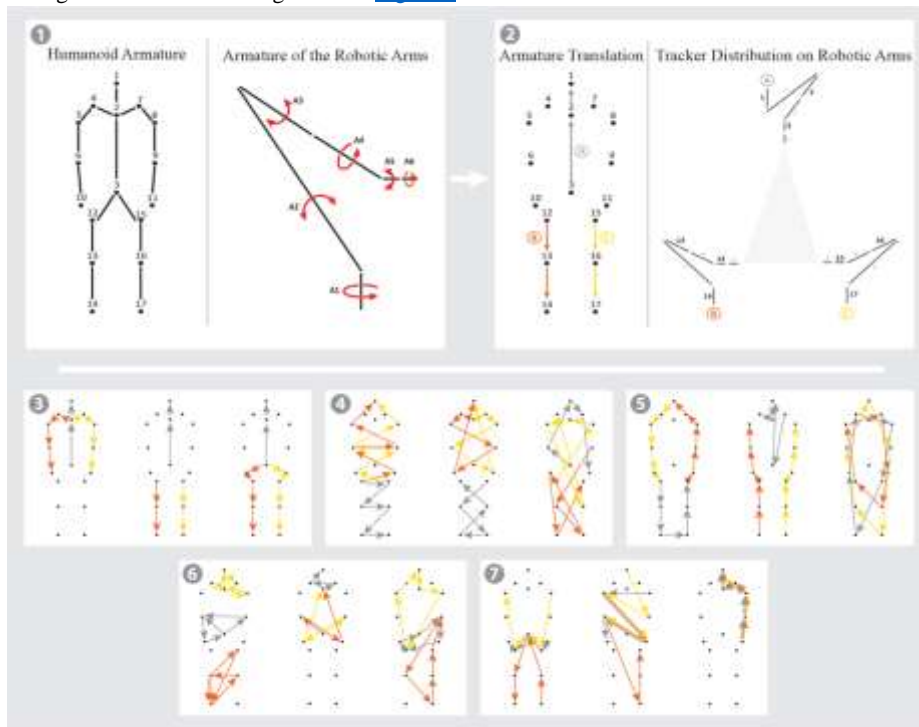


Figure 2: Image 1 compares the armatures of the MoCap system (humanoid) and the robotic arms. Image 2 shows the conceptual translation of MoCap sensors for the humanoid armature to the robotic arms. Images 3-7 show the various configurations used.

3.3 Procedure

Emergent relational body-textile expressions were explored through three explorations ([Figure 3](#)). Each used a different textile configuration in relation to the robotic arms, which were constant in terms of quantity and function throughout all explorations. Each exploration began with the robotic arms moving into a pre-defined default position, which caused the first sensing of movement that activated the continuous movement translation of the installation.

Exploration 1 used one triangular-shaped textile, which was connected at its end points to the ends, or sixth axis, of each of the robotic arms. This configuration allowed the textile to move and be moved as one body, which initiated movements in the robotic arms as much as it was moved by them. Exploration 2 used six triangular-shaped textiles attached to various points on the three robotic arms with respect to their six axes. This configuration allowed the textile to move and be moved as six separate bodies, which could move each other through their robotic extensions. Exploration 3 used a textile structure consisting of six elongated diamond-shaped textiles sewn together at various locations. This combined possibilities relating to the movement-related expressions of the previous two explorations by allowing parts of the textile structure to move independently, as well as the entire textile structure to be moved.

In addition, two sub-explorations were conducted for Explorations 1 and 2, and three sub-explorations were conducted for Exploration 3 ([Figure 3](#)). For Sub-Exploration 1, the MoCap sensors were placed in pockets that were stitched onto the textile in advance. This allowed the textile to act as the movement-sensing and -initiating agent; the robotic arms executed the movement commands in real time. For Sub-Exploration 2, movement-sensing and -initiating agency was given to the robotic arms by placing the MoCap sensors across the six axes of the three robotic arms that imposed movements onto the textiles. For Sub-Exploration 3, the MoCap sensors were placed on the body of a participant, who was recruited based on his expertise in performance and dance. His body movement was translated and animated the robotic arms, which moved the textile in the process.

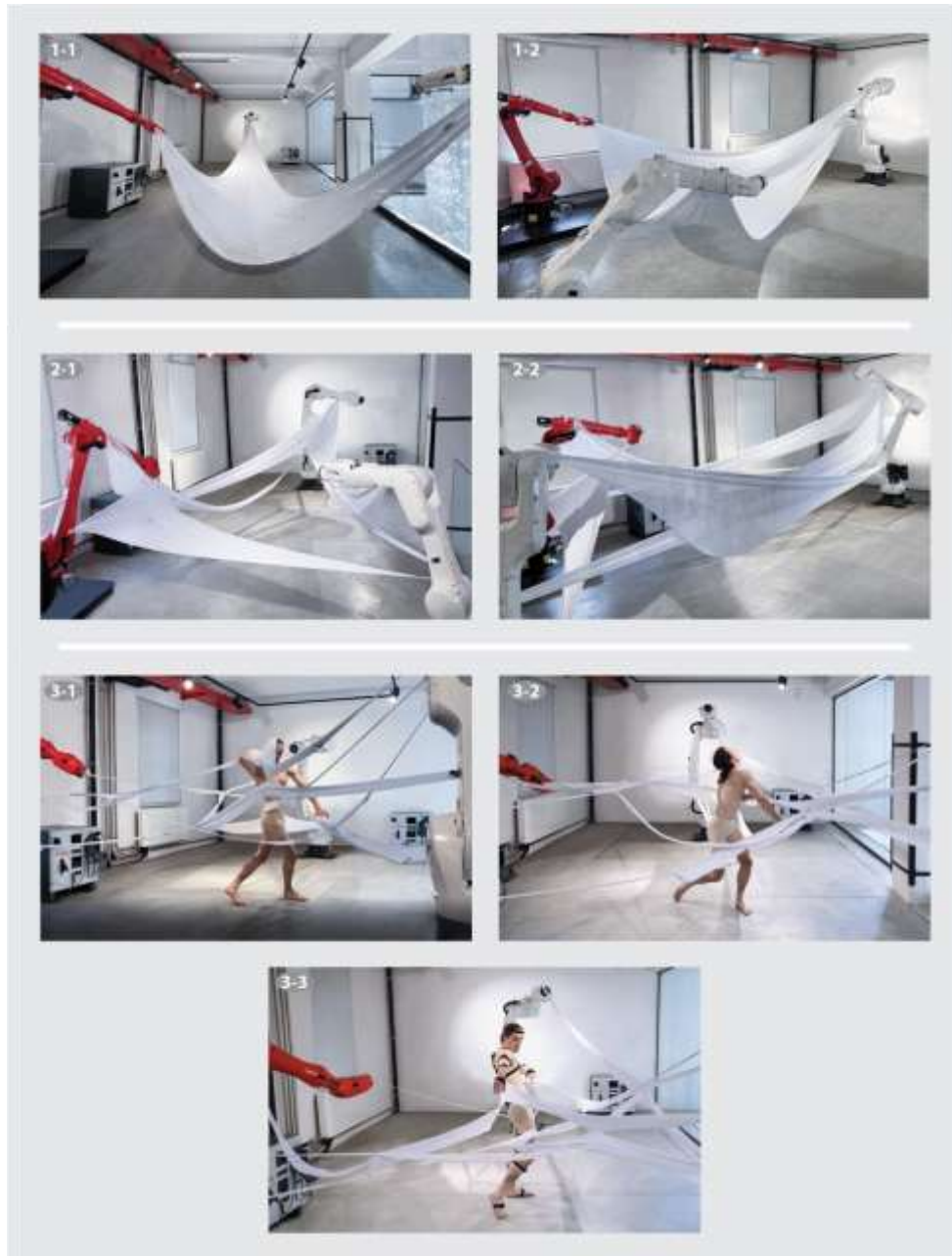


Figure 3: Rows 1 and 2 show Explorations 1 and 2, respectively, which were each split into two sub-explorations by placing the sensors on the textile (1–1 and 2–1) and robotic arms (1–2 and 2–2). Row 3 shows Exploration 3, which was divided into three sub-explorations by placing sensors on the textile (3–1), robotic arms (3–2), and body of a participant (3–3).

3.4 Data Analysis

The data analysis was guided by agential realism theory (see [Section 2](#)). In the first step, all explorations and sub-explorations of the installation were video-recorded from three different perspectives. This visually captured the relational movement expressions produced by the varying configurations of textiles, robotic arms, and the human performer. In the second step, the relational movement expressions of textiles, robotic arms, and the human

performer were documented by taking screenshots from the video recordings and organizing them based on the emergent hybrid body-textile expressions. By analyzing the visual material using intra-action theory, the intra-actions of textiles, robotic arms, and the human performer were found to suggest alternative ontological and hierarchical readings of the body and textiles, and to outline the agential role of data translation within that process.

4 Findings

The explorations that were undertaken during the research presented in this article led to four key observations concerning alternative ontological and hierarchical readings of body-textile relations, which were made possible through digital movement translation. All four key observations related to how textiles, robotic arms, and the performer's body engaged in a network of sensing and enacting movement. This ranged from circular movements in which the textiles and robotic arms directly and immediately affected each other through movement (Images 1 and 2 of [Figure 4](#)) to more complex and unpredictable movements caused by the human performer moving the textiles, which in turn equally affected him through their robotic augmentation (Image 3 of [Figure 4](#)).

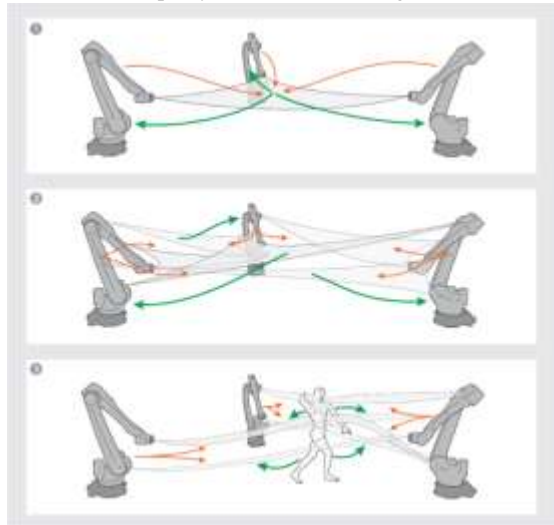


Figure 4: Sketches showing the textile-robot-human body configurations that were explored. The green arrows show the movement-initiating and -sensing process, while the orange arrows show the movement-responding and -enacting process.

4.1 Textiles and robotic arms as a hybrid-body system

Observations of Explorations 1–1, 2–1, and 3–1 suggested alternative hierarchies in what was perceived by the authors as movement-initiating and movement-responding bodies among textiles, robotic arms, and the human performer. Placing the MoCap sensors on the textile changed the textile's role, from responding to movements enacted upon it by other bodies to a sensing body that enacted movements on other bodies it was connected to. To enact movement, the robotic arms became reactive actuators of the textile that initiated movements based on the textile's 'commands'. While this shows similarities to existing research into how textiles can become sensing surfaces for movement translation [[16](#), [51](#), [52](#), [45](#)], the distinguishing feature of this installation was the space between the involved textiles, robotic arms, and human performer, which allowed for a different relational and hierarchical reading of them. This was particularly true for Exploration 2–1, wherein the textiles interacted with each other without being physically connected. Multiple textiles were attached to the three robotic arms without being physically sewn together. Despite the lack of physical connection between the textiles, they functioned as one hybrid body in the digital realm by reading the movement values of the MoCap sensors that were placed across all textiles in relation to each other. The resulting movement expressions showed similarities to moving bodies consisting of multiple limbs. However, what was novel with regard to the observations of this exploration was that these 'limbs', while connected to the robotic arms, were not connected to each other, and as such could move in parallel to and intertwine and disconnect from one another. Textiles and robotic arms thus became hybrid-body expressions that together performed movement with and through each other, based on movement data. As such, the

becoming of hybrid-body expressions through digital movement translation revealed the diffractive role of the data within the explorations. Relating this to Barad's definition of intra-action, movement data was involved in the shaping of body-textile expressions. The data transcended the role of representing either the body or textiles as separate, pre-existing entities, and enabled dynamic and mutual becomings.

4.2 Movement data as a material-transforming agent

Transforming textiles into movement-sensing actors by attaching MoCap sensors to their surfaces, as was done in Explorations 1–1, 2–1, and 3–1, meant that the movement expressions of the robotic arms were less clearly initiated by them. At various points during these explorations, the movements of the robotic arms seemed to relate more closely to textile movement in terms of acceleration, range, and patterns of movement. By gently swinging back and forth, repeating movement patterns with unexpected deviations, and becoming increasingly fluid, continuous, and organic, the movement expressions of the robotic arms seemed to be more associated with textiles than robotics. In Exploration 1–1 in particular, the robotic arms occasionally swung back and forth in synchronicity with the textile that was attached to them. As such, they became less visible as outside actors that were imposing movement on the textile; instead, the textile seemed to expand from its material origin towards the limbs of the robotic arms because of its movement expression. By comparison, in Explorations 1–2, 2–2, and 3–2 movement was initiated in the robotic arms by attaching the MoCap sensors to them rather than the textile, resulting in movement expressions that changed in terms of acceleration, direction, and movement range and seemed to be visually disjointed from the movement of the textile. Comparing these observations suggested that the handling of digital movement translation and the movement data not only led to the emergence of hybrid body expressions, but influenced the movement-expression-based boundaries of the involved entities. It was possible to impose textile-related movement expressions on the robotic arms by placing the MoCap sensors on the textiles. Relating this to Barad's concept of intra-action, the intentional use of movement data facilitated the diffraction of body-textile expressions by extending the movement expressions of textiles to the robotic arms. As such, they were no longer entities that solely reacted to one another, and instead became movement-based, data-driven hybrids that expressed themselves through an emerging, entangled means of communication.

4.3 Reconfiguring hierarchies of textiles, robotic arms, and the human performer

Observing the intra-actions between the human performer and the textile-robot installation in Exploration 3–1 suggested a mutual dialogue between all involved agents, with each equally active and reactive to one another. The human performer responded to the movement-sensing textiles; these were attached to the robotic arms, which in turn enacted movements on the textile. The contractions and expansions of parts of the textile structure that resulted from the movement of the robotic arms continuously changed the space in which the performer was able to move. As such, the performer needed to change position and posture in order to remain standing when the textile moved closer to him and intersected with other parts of itself. Consequently, the performer moved not only his body but also the sensing textile by rotating it around himself, lifting it over his head, and moving underneath it. The textile 'responded' to this by moving with the help of the robotic arms in different positions and configurations, which in turn demanded reactions by the performer. Observing the dynamic between the textile, the robotic arms, and the human performer over a longer period of time revealed transitional textile expressions, including a garment-like material expression when the textile was covering the body to one where the textile itself resembled a body that was moving through space because of its movement-sensing and -enacting qualities. As such, the textile, robotic arms, and human performer engaged in an entangled act of becoming that dynamically shifted their roles based on their movement-related engagement. Contrastingly, the textiles in Explorations 3–2 and 3–3 were subordinate in their movement-sensing and -enacting agency, on the basis that they reacted solely to the movements of either the robotic arms or the human performer when the MoCap sensors were placed on one of these. With regard to Barad's concept of intra-action, this suggests that the data not only translated movement from one entity to another, but changed the hierarchies between them in terms of how they engaged with one another. Giving movement-sensing and -enacting agency to the textile through data processing facilitated dynamic expressions of (un)dressing and (de)forming to emerge that may not have been possible were it not for the shifting role of data – from representing phenomena to an entangled, design-related agent that shaped relational expressions.

4.4

Entangled agency of movement data

The unpredictable translation of movement expressions by the textile-robot installation suggested that movement data can function as both a design material and an autonomously acting agent for creating hybrid body expressions. Setting up 15 sensor configurations, as discussed in [Section 3.2](#), did not result in any changes in the expressions of the movements of the robotic arms that could be clearly traced back to the sensor configuration that was active at any given time. The movements of the robotic arms seemed to generally be random, which made it difficult to predict whether the movement translation was based on Sensor Configuration Theme 1 or any of the other four themes. While this seemed to be a failure at first, it gave more agency to the textile-robotic system in terms of how it interpreted and generated movement from a conceptual point of view. Consequently, the abstraction of movement input that was performed by the textile-robotic installation and how this enacted physical movement expressions through textiles and robotic arms created the impression of a more autonomously acting hybrid-body system due to the added degree of unpredictability. This was particularly the case in Explorations 3–1, 3–2, and 3–3, where the degree of unpredictability led to movement-based dialogues between the textile, robotic arms, and human performer wherein no single actor dominated the others. It was concluded that the reason for this was that the human performer could not predict how the textile-robot installation would move based on recognizable movement patterns over time, and so was unable to adjust to recurring movement patterns and instead had to continuously improvise based on the ever-changing movement expressions of the textile-robotic installation. Considering these observations through the lens of intra-action theory reveals the entangled nature of movement data in the creation of hybrid body expressions as part of the textile-robot installation. Despite the sensor configurations being developed prior to testing the installation, they were constituted by the placement of the MoCap sensors on the textiles, robotic arms, and human performer, as well as the movement range and armature of the robotic arms. The physical setup affected the movement data as much as the data affected the movement of the textiles and bodies. As such, the movement data functioned as a design material that was not fully predictable in its agency due to its entangledness.

5 Discussion

The findings of the research presented in this article suggest a greater degree of conceptual openness in terms of how data is handled in the context of digital fashion can contribute to a technologically evolving design discipline. This conceptual openness needs to be rooted in a shifting understanding of data relating to expressions of the body and textiles, and seeing data as a design material that can lead to intra-acting physical-digital material engagements [\[40, 41, 53, 60\]](#). Data can function as a design material in digital fashion to define, distinguish, emphasize, disrupt, amplify, and distort expressions of the body and textiles, which do not rely on the traditional distinction between the two that is rooted in the physically based history of fashion [\[33, 34, 55, 65\]](#). Instead, body and textile expressions can be hybrid, amorphous, temporal, and dynamic, enabling an alternative material understanding that situates the body and textiles within a dynamic and temporal ontology and hierarchy [\[64, 66\]](#). Data can move from a representationalist role that is hidden from the fashion designer to being at the forefront, as an actor, interpreter, transformer, and design material that is entangled with its context and the designer's view.

Bringing awareness to the role of data in its agency in terms of shaping expressions of the body and textiles within fashion may help in regarding digital technology such as three-dimensional scanners, MoCap systems, and three-dimensional CAD software as more than tools for digital garment construction [\[55, 65\]](#). Rather than taking how the body and textiles act, react, and function in digital environments to be given and pre-defined, fashion designers could question and interact with data as a material for design in order to blur expression-based boundaries and explore the body and textiles as equally designable entities. Engaging with data as a translator of phenomena between the body and textiles allows designers to reconfigure body-textile expressions and build on a conceptual sense of togetherness, rather than a dichotomic view of the body and textiles as pre-existing entities.

Beyond fashion design, the findings contribute to growing discourses on the use of intra-action theory and post-humanism within the HCI community. Through their entanglement during the explorations, textiles and robotics had an equal influence on each other based on their movement translation, and as such blurred the movement-based boundaries between them that suggested a shift toward hybrid body-textile configurations. Textiles, as sensing and movement-enacting bodies, raised post-humanist questions relating to which bodies technology can engage with, how they can do so, which bodies technology could be developed for, and what investigations of this kind can reveal about technology's role and affordances in non-human contexts. Furthermore, the findings suggest the potential of improving MoCap techniques and methods for non-anthropomorphic bodies such as textiles. Within the field of

smart textiles, research could be conducted regarding how MoCap sensors could be woven into textiles without interfering with the textile movement by adding weight or making the parts of the textile where object-based sensors would be attached rigid. Additionally, digital-computation researchers could develop MoCap methods that are designed especially to capture textile movement. Since textile bodies do not consist of rigid limbs with joints between them, alternative methods of motion translation would be needed to fully capture movement expressions specific to textiles.

Future research could test more MoCap systems in relation to movement translation to further explore the agential role of MoCap technology and data in intra-active body-textile expressions. Furthermore, working with a wider variety of textiles may reveal the changing levels of agency textiles can hold for emerging hybrid movement expressions.

Closing remarks

This research suggests creative approaches to digital translation processes of phenomena such as movement, which can be used to create hybrid body-textile expressions based on intra-action theory. The body-textile installation showed that data and its translation as an entangled design material can overcome dominant dichotomies relating to the body and textiles in fashion design. The research presented in this article contributes to an increasingly becoming digital design discipline by suggesting conceptual openness toward relational affordances and meanings of the body and textiles when experienced and engaged with through digital technology.

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