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Rethinking Bodily Expression in Human-Robot Communication: Insights from Sculpture

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Abstract. Sculpture offers a centuries-long tradition of techniques for expressing emotion and movement in a static form. Insights from this field present an opportunity to design robots that express not only through movement, but also via dynamic cues in their static positions. Such cues can suggest motion potential, emotion, and character. This paper presents three principles identified in sculpture techniques that can be applied to robot design: (a) depicting exposure and protection of emotional pivot points in the body, (b) weight distribution, and (c) the revelation of movement mechanisms and tension through flexible skins. We employ the first two of these principles in an interactive design and motion control environment to demonstrate the potential for application to the design of social collaborative robots. We illustrate the third principle via a robot design that uses a flexible fabric skin stretched over rigid and elastic actuation elements. Using insights from sculpture can promote the design of robots from a transdisciplinary perspective by increasing the readability of robot intent and affect even when the robot is not actively moving.

Keywords: Social robotics, sculpture, interaction, design, human-robot interaction

1 Introduction

As interactive robots are developed for socially intimate applications as described, for example, in Zuckerman and Hoffman [1], the need for these robots to be expressive and evoke an affinity to their internal states is gaining a central focus in the robot design community. In fact, Fong et al. [2] have long suggested that a robot's ability to express emotion via natural cues is a requirement for it to be considered socially interactive.

In light of this requirement, social robots have been designed to express emotions and intent through a number of verbal and nonverbal channels. The nonverbal modalities generally include the robot's morphology and appearance on the one hand, and its movement and gestures on the other [3, 4]. In anthropomorphic robots, facial features can be used to articulate emotions, either in actuated features [5] or on a screen display [6]. Other avenues for nonverbal communication of robotic emotions or intentions include path planning [7], lighting patterns [8], and proxemics [9]. For the most part, movement is emphasized as the preferred expressive modality for social robots. For example, Hoffman and Ju [10] promote the value of movement over appearance in robotic expression, emphasizing human sensitivity to physical movement and spatiotemporal affordances.

Robot movement, however, has its limits and shortcomings as an expressive medium for social communication. The movements of robots are almost exclusively expressed through rigid limbs connected at major skeletal joints, such as the neck, shoulders, elbows, hips and knees. This design choice can result in movement that is unlike human expression and is characteristically stiff. These "robotic" movements are then complemented with other quite unnatural communication modalities, such as on-screen messages and images, alarms, or LED lights.

Against this context, we suggest considering the design of social robots from a different human-centric perspective, supporting the capacity for robots to communicate through non-movement means, which could equally convey an intuitive body language. The robotic body language we propose here is based on sculpture, a broadly understood method of communication embedded in a long historical context. The use of nonverbal and non-written communication can also form a democratizing approach, offering broader access for people to engage with robotic technology, without the need for specialist technological knowledge or training.

Our proposal also has a pragmatic side. In focusing only on dynamic movement when looking at a robot's nonverbal behavior, designers are missing out on the opportunity for a robot to emote and express when it is not moving. Moreover, ignoring the emotion expressed in static positions can undermine the authenticity of gestures when the robot returns to a resting pose between each movement. Humans, in contrast, are continuously communicating their internal affective state, even as they relax, sit, stand, or sleep.

In support of our proposal, Coulson [11] found that participants could readily parse emotions in static pose images of computer-generated mannequins. In contrast, though, when Bretan et al [12] experimentally evaluated the expressive nature of a robot's postures and dynamic gestures, they found that static postures do not convey emotions as well as dynamic gestures. However, in looking at Bretan et al's experiment we question whether the robot was originally designed to communicate through static postures? One can read the results from their experiment as a call to action, encouraging designing a robot's static poses to be as expressive as its movement. To the best of our knowledge, no research in social robotics has specifically investigated the intentional design of emotional expression through static poses.

To tackle this challenge, we have engaged in observational analysis of sculptural forms to understand the role static aesthetics can play in robot design, and the ways in which these aesthetics can express emotion, movement potential, and mood in a natural and readable manner. We consider emotional expression in three stages, moving from the body's internal state, to the external. We begin with the 'protection' or 'exposure' of what we have identified as 'emotive pivot points' within the body, to the communicative role of weight distribution and finally to external material compression and extension.

The works chosen to illustrate each point have been selected from the Western classical and contemporary canon and are therefore limited in scope. The presentation of these works is, however, not intended as a comprehensive survey or taxonomy of emotion expression techniques in sculpture. Instead, it is an illustration of potential transdisciplinary insights from the field of sculpture to that of robot design, supporting the case for a scholarly conversation between these areas of research.

In light of this motivation, one can understand the selection of works presented below as *curation* [13], in the sense that their display is not simply about making established knowledge tangible and accessible, but rather that the selection and juxtaposition of these works form new knowledge, or a new 'way of knowing, [and] a particular way of relating to the world' [14]. The presentation of these works within the context of human-robot collaboration places them in dialogue with one another and a new disciplinary field, inviting viewers to explicate a thematic interpretation of the artifacts (see: [13]). Additionally, toward illustrating the tangibility and potential application of this transdisciplinary research, we demonstrate how this proposed approach can inform a simplified robot control system, and the design of an abstract expressive robot model.

2 Background

From the earliest examples of biologically inspired robots, such as the robotic tortoises built in the 1940's [15] through to HiBot's robotic snake presented in 2013 [16], researchers have been interested in how mimicking the form and movement of humans and animals can improve the functionality of robots or imply social principles through the recognition of particular body parts or gestures.

Increasingly, researchers have worked to endow social robots with the capacity to perceive and express emotional states through a range of modalities. Some more complex examples of these works include Breazeal's "Leonardo" [4], a 65-degree-of-freedom (DoF) robot that used human-like gestures and was able to mimic human facial expressions. Another example is "Paro" [17], a therapeutic robot in the form of a baby harp seal, who communicates through zoomorphic body language, responding by moving its head and legs and vocalizing seal sounds to show pleasure or distress. Some non-anthropomorphic interactive robots use their bodies to act out "enjoyment" of music [18], light patterns to communicate social ties [8] or fear [19] and proximity to display affection [9]. In more recent years, the designers of commercial humanoid robots such as "ARI" from PAL Robotics [20], and Softbank's "Pepper" robot [21] have combined the use of expressive eyes and human-like gestures together with an interactive tablet mounted on the robot's chest to boost the communicative capacity of the robot.

From the available reports, the designs of these robots were driven by functional or aesthetic considerations. Movement was sometimes added to the expressive capabilities of the robots and sometimes taken into consideration from the start as part of the morphological design. That said, we do not know of robots that were specifically designed with an eye toward the expressive capability of their static poses.

Interaction Design and Architecture(s) Journal - IxD&A, N.61, 2024, pp. 98 - 116
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This paper looks to sculpture to understand the way in which indicators of emotion and affective states in the human body can be expressed in a figure or form, not only during movement but also in static states. Through a curated set of examples, we investigate the exposure and protection of major emotive points in the body, weight distribution, and the role of flexible materiality in conveying emotions, and how these might be translated to a robotic form.

3 Insights from Sculpture

In its origins, representational sculpture pursued a “scientific idealism” [19] seeking to represent the purportedly ideal human body in an anatomically precise manner. In addition, however, sculptors also sought to depict dynamic poses and expressive arrangements that suggested movement and affect. As modern and contemporary sculpture moved toward abstraction, aesthetic principles concerning movement and the embodied representation of emotion were distilled and applied to more basic forms. This historical refinement of expressive techniques, although they originated from the human form, can therefore be readily applied to the design of non-humanoid robots in the same way they are employed in the semiotics of minimalist and abstract sculpture.

Fig. 1. Ron Mueck, *Boy*, (1999), Mixed media, La Biennale di Venezia, 2001 © Ron Mueck. DACS/Copyright Agency, 2024

Many social robots can be seen “resting” or shut off in an upright position. After such robots perform movements or gestures, they most often return to their programmed neutral position. What if robots were animated even in their resting state?

Interaction Design and Architecture(s) Journal - IxD&A, N.61, 2024, pp. 98 - 116
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This idea can be demonstrated through the work of contemporary artist Ron Mueck. Mueck's *Boy* (Fig. 1) is crouched low and lightly rests his hands on his head, watching carefully beyond his arms. From this low, watchful and tightly curled pose, we get a sense of his character. He is animated even as a static sculpture: his pose tells the narrative of movement both before and after the current stance. He is embedded with the "story" of movement. In the same way, one could imagine a robot assuming a crouched or curled resting position to indicate its potential for movement into and beyond that pose or speak to its emotional capacity or character.

To understand how movement and emotion might be practically implemented in the design of social robots, we have distilled our observations from sculpture into the following three principles, and, in the section below, we illustrate the key aesthetic elements of each idea, toward application to robot design.

3.1 Principle 1: Exposure and protection of emotive points in the body

In the design of social robots, movement joints are usually situated at major skeletal joints, for example the base of the head and pelvis. Beck et al. [22], for example, identified head pose as an important body posture variable in robot bodily expression. At the same time, other areas such as the upper torso and mid-neck usually remain rigid, as seen in both previous examples of humanoid robots, ARI [20] and Pepper [21].

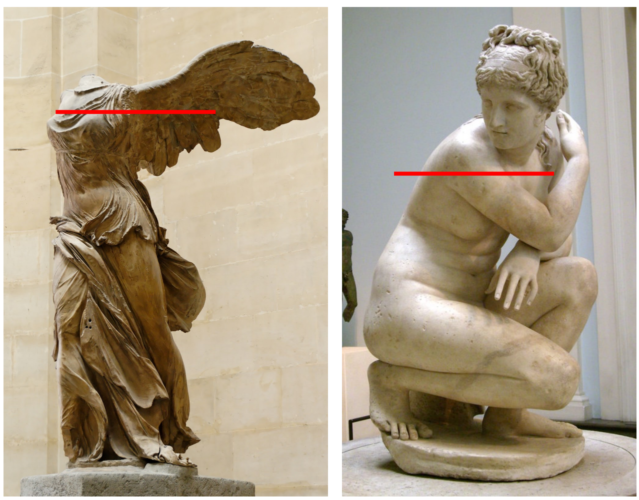

Fig. 2. Left: Pythokritos of Lindos, *The Nike of Samothrace,* (C. 200- 190 BC) Parian Marble, Louvre, Paris. Creative Commons. Right: Paolo Alessandro Maffei, *Crouching Venus,* (1704) Marble, Uffizi, Florence. Creative Commons.

However, when we analyze and compare sculptural works such as those in Fig. 2, we see that the catalyst for projecting different emotions is in a deformation indicating exposure or protection of the center of the chest. Fig. 2 (left) shows the Nike of Samothrace projecting her chest forward in pride and defiance; in Fig. 2 (right) we see Venus curled in, guarding her chest in modesty and self-protection.

Areas on the body such as the face, neck, chest, shoulders and hands can be either exposed or protected in the pose articulated by sculpture artists in order to convey a range of emotions from strength and pride to fragility and introspection. These gestures are often embodied in the shape of the emotive body parts in question. In the work of contemporary British sculpture artist Antony Gormley in Fig. 3, we again see the use of complete exposure of a straight torso in contrast to protection by curling the torso and neck, as a means of conveying strong emotional affective states in static figures.

Fig. 3. Left: Antony Gormley, ANGEL OF THE NORTH, (1998), Steel, Commissioned by the Gateshead Metropolitan Borough Council, Gateshead, England, Permanent installation, Gateshead, England © the artist, Gateshead, England. Right: Antony Gormley, CLUTCH, (2007), Variable mild steel blocks, 95 x 44 x 85 cm, Photograph by Stephen White & Co. © the artist.

Consider also the works below by Italian artist Matteo Pugliese in Fig. 4. The exposure of the neck and face is coupled together with a convex vs. concave chest to further emphasize the intensity of the pose. We can also see how the exposure of the palm of the hand signifies a different emotion to the *Boy* in Fig. 1, where the hands are closed, protected and drawn in close to the body.

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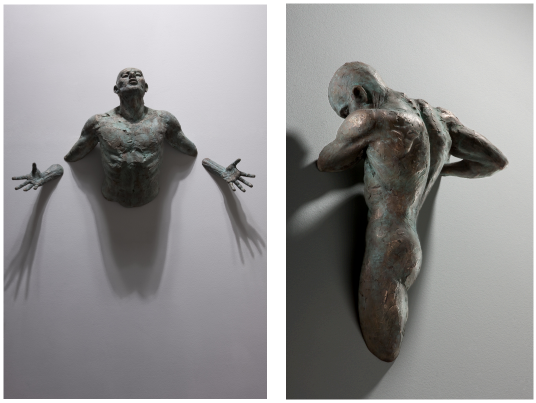

Fig. 4. Left: Matteo Pugliese, *La Promessa*, (2010), bronze, © the artist. Right: Matteo Pugliese, *L'Ultra Chance*, (2010), bronze, © the artist.

Exposing or protecting emotional body locations in the human form relies on a multi-joined torso. To simulate this in a robotic form would demand additional degrees of freedom in addition to the common skeletal joints at the top and bottom of a rigid torso. An example of a robot design decision inspired by this principle would be adding additional joints to areas that might aid emotional positioning, such as the center of the chest, or the center of the neck.

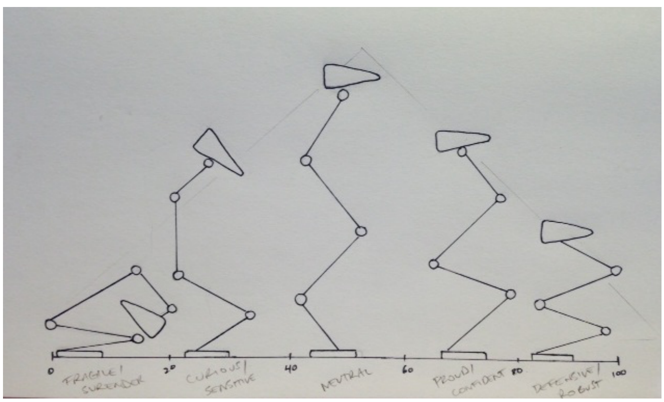

Fig. 5. Author's sketch: emotional pivot points.

Fig. 5 demonstrates this idea via a sketch using multiple torso joints at the identified emotional points. This configuration allows for the chest, neck and head to be projected, or curled in a protected position, allowing the animated figure to move or pose in an emotional way. Fig. 5 also demonstrates contrasting poses that are equivalent in height, but project different emotional stances based on the relative configurations of the

Interaction Design and Architecture(s) Journal - IxD&A, N.61, 2024, pp. 98 - 116
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internal torso joints. We will further demonstrate this principle in the context of robot design using the computational model described in Section 4 below.

3.2 Principle 2: Weight Distribution

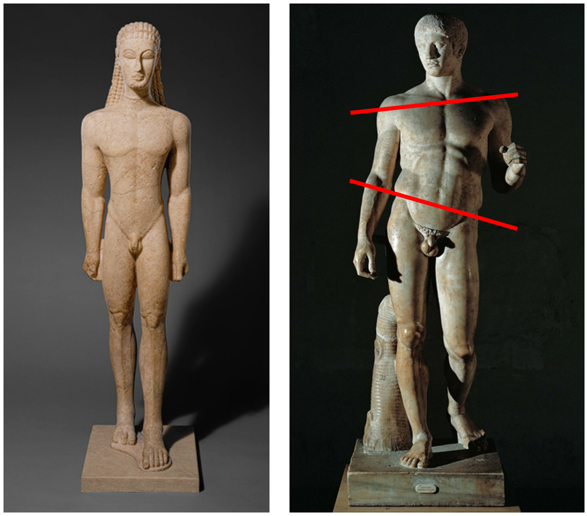

Fig. 6. Left: *Statue of Kouros* (c. 530 BC) Marble, Metropolitan Museum of Art, New York. Creative Commons. Right: Polykleitos, *Doryphoros* (440) Marble, Museo Nazionale, Naples. Creative Commons.

One of the first major developments explored in Greek sculpture was the implementation of *contrapposto* [23] (Fig. 6, right), an Italian term meaning counterpoise, a compositional device referring to the redistribution of weight to one leg and tilting of the hips and shoulders to convey a more dynamic and relaxed stance. Compare this technique to earlier works, for example the statue of Kouros (Fig. 6, left), which presents a symmetrical and balanced stance. Contrapposto was used to convey a calm emotional state, which was considered an integral component of the concept of the idealized man. From this first development of dynamic posture, Greek sculptors went on to explore how the static form could convey a whole range of human experiences [24].

In applications such as those proposed by Zuckerman and Hoffman [1], including couple's communication, classroom activities and mediation and conflict resolution, the ability of a robot's resting pose to express either tension or relaxation has the potential to enhance the interaction. One-off dynamic movements, such as the shivering action employed by Zuckerman and Hoffman, are ill-suited to consistently convey the spectrum between tension and relaxation. In contrast, weight distribution may be a way for robots to express such nuanced internal states, which could be differentiated from simply being shut off.

Interaction Design and Architecture(s) Journal - IxD&A, N.61, 2024, pp. 98 - 116
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In the contrapposto stance (Fig. 6, right), the figure shifts weight to one foot to indicate relaxation, however, humans and animals also redistribute their weight in response to a threat, or to brace themselves, by lowering their center of gravity, just as a boxer might do in preparation to fight, or a snake in preparation to strike. In the example of the Greek sculpture of *Atlas* (Fig. 7), the primordial titan bears the burden of the celestial sphere. The sculptor has indicated the weight of the sphere through the pose that Atlas adopts. He has lowered his body weight and center of gravity and is braced with his legs against the strain. Even as Atlas and the globe are carved from one block of stone, his struggle and affective state can be perceived through his pose and weight distribution.

Fig. 7. *Atlas, Titan of Strength*, (2nd Cen BC) Marble, National Archeology Museum, Naples. Creative Commons.

In application to robotics, the balance of weight and height of the robot's center of gravity can communicate a range of emotions from casual relaxation, through emotional and physical alarm, to effort. Even though a mechanical or emotional struggle may not be present, we can communicate the narrative of comfort or discomfort through weight distribution.

In the computational model described in Section 4, the pivot points are connected to both a horizontal weight shift, and to a Z-shaped crouching and stretching of the lower body, allowing for a sense of weight and deliberate distribution and movement.

Interaction Design and Architecture(s) Journal - IxD&A, N.61, 2024, pp. 98 - 116
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3.3 Principle 3: Material Compression and Extension

The third principle we propose to borrow from the practice of sculpture is the emotive potential expressed through folds of skin and cloth. In the example of the human hand (Fig. 8), we recognize the potential for movement, even when the hand is static and relaxed. We receive cues for this potential from the compression, extension, and tightening of the skin, which allows for movement mechanisms such as bones and tendons to show through. In the example depicted below, the difference between a closed hand and a clenched fist is the application of muscle, visible through the skin, potentially conveying two very different internal states.

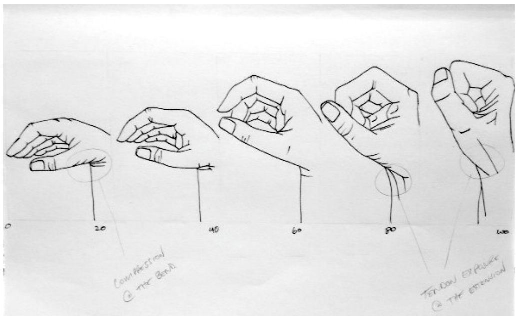


Fig. 8. Author's sketch: hand expression through skin folds over bones, muscles, and tendons.

When we look at the compressed folds of skin, they carry the potential for movement in their ability to unfold, like the creases of an accordion. When the skin is pulled tight, the force of the muscle pulling the skin is made evident as the mechanisms in the form of bones and tendons are brought to the surface. The skin or materiality demonstrates the extent to which muscle has been applied or relaxed, and with it, the intensity of the emotion or movement in the pose.

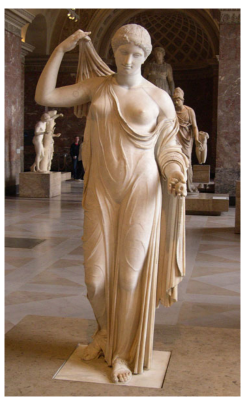


Fig. 9. *Aphrodite "Venus Genetrix"* (c.2nd AD), Marble, Musee de Louvre, Paris, France. Creative Commons.

Interaction Design and Architecture(s) Journal - IxD&A, N.61, 2024, pp. 98 - 116
DOI: 10.55612/s-5002-061-003

The concept of compression and extension of soft materials, including skin, fat, muscle, and fabric, was embraced in the first dynamic sculptures of the human form and was capitalized on by Greek sculpture artists. The Greeks were among a tradition of sculptors who carved draped fabrics across the bodies of their subjects to articulate the relationship of movement between different limbs, emphasizing the pose and the body [25] (see: Fig. 9).

Emphasizing the function of robotic actuators and the subsequent folding of soft layers could be a powerful means to convey emotional intention in their movements. We propose that elastics, fabrics, and other responsive materials that flex and fold to connect rigid elements of the design can demonstrate compression and extension, emphasizing the movement potential and emotional severity of the static pose. Material connections that stack loosely or pull tight between two parts of a robot may indicate a relationship between those mechanisms. The exposure, through a fabric layer, of movement mechanisms such as springs may also play a similar role to the exposure of tendons or straining of muscle.

4 Computational Model and Simulation

To demonstrate the applicability of the first two principles outlined above to the design of socially expressive robots, we developed a 3D simulation environment enabling us to explore structural parameters and motion control. A screenshot of the simulation environment is shown in Fig. 10. The simulation environment enables robot designers and motion control engineers to explore the potential design space of a new expressive robot structure, following on the tradition of interactive design tools such as that described by Igarashi et al [26]. Our system is specifically built toward designing expressive robots, as the structure is built around single DoF (degrees of freedom) joints, and its interactive user interface (UI) is set up to explore DoF relationships, distances, and control relations.

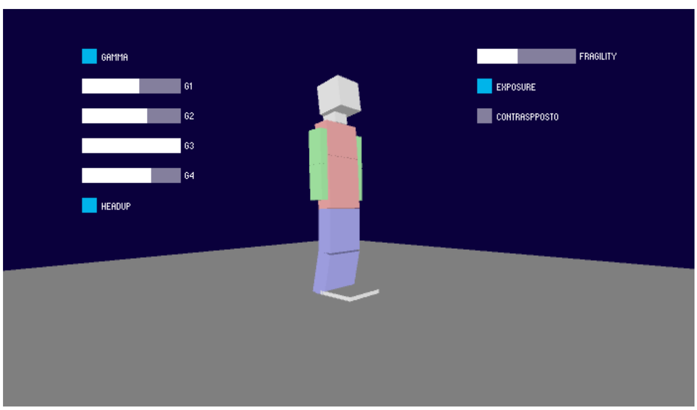


Fig. 10. Interactive Design and Simulation Environment.

We acknowledge that the translation of complex human emotions to limited control parameters is an inherently reductive process. However, the focus of this tool is to show a pragmatic path forward and support the transdisciplinary potential of our analysis by illustrating how the abstract principles identified above can lead to specific design methodologies that can be used in the field of social robot design.

In addition, the presented simulation and design tool points the way to the design of low-cost, low-DoF robots, which make use of multiple-action linkages (MALs) allowing for more than one movement using the control of a single motor [27]. In MALs, one actuator controls several distinctly moving parts, and can even cause different directions of movement throughout the trajectory of a single motor. We use MALs both for their economy and mechanical elegance, as well as promoting the accessibility of this method. Designing principles for application to low cost, low-DoF robots allows students and researchers with limited means to design for expressive movement without the need for high-end actuated features or complex systems.

In the interactive simulation environment described herein, we chose to have only a single control variable, which we denote *fragility* (denoted *f*). This parameter affects a number of expressive static features, based on the above survey of insights from sculpture. In particular, we implemented the ideas of *exposure* of emotive points, such as the chest, and *weight distribution*, both vertically and horizontally. We discuss the application of *materiality* in the next section.

It must be added that the complex notion of fragility can clearly not be fully codified through the application of two insights from sculpture and a single control parameter. In fact, fragility has been investigated through a variety of intentional design techniques in HRI, for example through the use of materials [28] or armors [29]. In this section, we instead show how it is possible to integrate a principle from sculpture as a design and control parameter to motivate the transdisciplinary inspiration we suggest in this paper.

Table I summarizes the simulated mechanical components and their relationship to the above-mentioned insights from sculpture. The rest of the section elaborates on our structural parameters and control relationships.

Table 1. Mechanisms and sculptural elements

Mechanism	Sculpture Element
Segmented chest	Exposure of chest emotive point
Actuacted head	Exposure of neck emotive point
Two-link arms	Exposure of chest emotive point
Two-link legs	Vertical weight distribution
Actuated hips and shoulders	*Contrapposto* weight distribution

4.1 Exposure of Emotive Points

We implement the principle of exposure and protection using three mechanisms (cf. Table 1):

- A segmented chest capable of convex and concave movement. In practice, this can be achieved with a cable driven link mechanism similar to an underactuated robotic grasper (e.g., [22]). This design allows us to implement the exposure and protection of the chest as an emotive point.
- A head actuated at its base, enabling us to implement the exposure and protection of the neck as an emotive point.
- Two-link arms that are capable of folding in front of the chest, also allowing us to implement the exposure and protection of the chest as an emotive point.

In our simulation, we drive the chest and neck exposure using the single fragility driving parameter f mentioned above. The mechanical structure of the robot is adjustable by three parameters: a scalar Γ_1, defining the extent of the curvature; a scalar Γ_2, defining the relative bend between the chest links; and binary variable B_1, defining whether the neck is protected by the head or not.

The control equations are as follows, with C_1 denoting the base torso rotation, C_2 denoting the mid-torso rotation (in this case, it is a two-link chest, but this is readily generalizable to multiple links), H_1 denoting the head base rotation, A_1 denoting the shoulder rotation, and A_2 denoting the elbow rotation. For readability, we ignore constant scaling for angle conversion.

$$C_1 = -f \cdot \Gamma_1 \cdot \Gamma_2 \tag{1}$$

$$C_2 = -f \cdot \Gamma_1 \cdot (1 - \Gamma_2) \tag{2}$$

$$H_1 = \{ \quad \begin{array}{l} \text{if } B_1 : \ \text{abs}\,(f \cdot \Gamma_1) \\ else: -f \cdot \Gamma_1 / 2 \end{array} \tag{3}$$

$$A_1 = (f - ½) \cdot \Gamma_1 \tag{4}$$

$$A_2 = \max(0,\ f - ½ \cdot \Gamma_1) \tag{5}$$

4.2 Weight Distribution

We implement the principle of weight distribution using two mechanisms:

- Two-link bending legs, allowing us to shift weight vertically.
- A roll-actuated hip and shoulder joint, allowing us to shift weight horizontally.

We drive the weight distribution joints using the same single driving parameter f denoting the emotive scale of fragility. The mechanical structure of the robot is adjustable by two parameters: scalar Γ_3, defining the extent of the vertical weight distribution, and Γ_4, defining the extent of the *contrapposto*.

The control equations are as follows, with L_1 denoting the ankle rotation, L_2 denoting the knee rotation, W_1 denoting waist rotation, and S_1 denoting the shoulder roll rotation. Again, for readability, we ignore constant scaling for angle conversion.

$$L_1 = \mathrm{abs}\,(f - \tfrac{1}{2}) \cdot \Gamma_3 \quad (6)$$

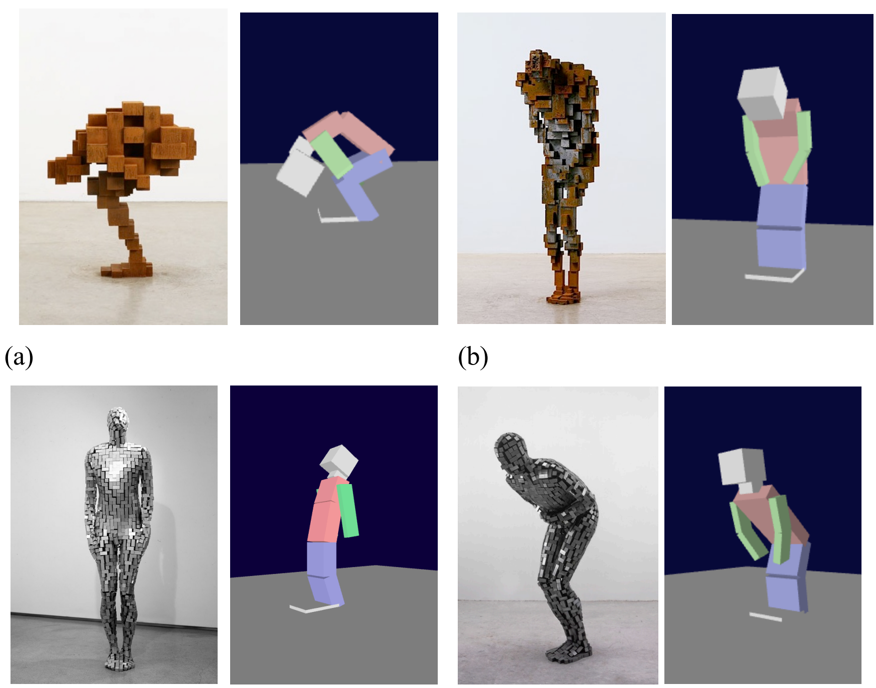
$$L_2 = -\,2L_1 \quad (7)$$

$$W_1 = (1 - f\,) \cdot \Gamma_4 \quad (8)$$

$$S_1 = -\,(1 - f\,) \cdot 2\,\Gamma_4 \quad (9)$$

Note that all of the motion control in the model is driven by a single emotive parameter, fragility (f). One can think of this as having a single slider controlling the full range of expression for the robot model, or a single motor actuating all of the robot's pose through mechanical linkage alone. In that context, the control parameters Γ_i and B_1 are not on-line control drivers, but instead offer structural variations in the mechanical design of the robot.

4.3 Explorative Design Evaluation



(a) (b) (c) (d)

Fig. 11. Range of Expression / Pose comparisons with sculptural works by Antony Gormley: Antony Gormley, CLUTCH VIII, (2010), Cast iron, 93 x 45 x 78 cm, HAFT II, (2008), Cast iron, 160 × 50 × 66.5 cm, BUILDING VI, (2004), Variable stainless steel blocks, 191 x 53 x 36 cm, Musée des beaux-arts de Montréal, Montreal, Canada, GUT V, (2002), Variable mild steel blocks, 152 x 51 x 72 cm, Photographs by Stephen White & Co. © the artist; All sketches use the same mechanical parameters, except B_1 in (d). Specifically: a) f=1.0 b) f=0.53 c) f=0.07 d) f=0.72 (B_1=true).

Interaction Design and Architecture(s) Journal - IxD&A, N.61, 2024, pp. 98 - 116
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The following examples (Fig. 11) demonstrate the range of expression articulated in the simulation environment, placed alongside poses from sculptural works by Antony Gormley. The images demonstrate the range of dynamically expressive poses achieved with static poses using only a single control DoF in combination with properly adjusted Multi-Action Linkage parameters.

We propose that a tool such as the design exploration system described here can be used to interactively map emotive robotic poses based on design sketches, as well as to plan emotive resting poses, expression of robotic character, and placement of mechanical components in the robot's design.

5 Material Skin as Expressive Medium on a Physical Robot

The first two principles we identified were concerned with the placement of body parts in relation to each other. They therefore offered themselves to the preceding illustration of the rigid-component simulation. The third principle is more related to the depiction of material properties surrounding the skeletal form in sculpture. While this principle could also be illustrated using computational material simulations, we are able to demonstrate the idea of material compression and extension via *Blossom*, an existing robot that uses a flexible skin over rigid ("bone") and elastic ("tendon") components. The robot's design allows for morphological aspects of the robot that can fold or extend to emphasize movement and to express in the robot's static poses.

Fig. 12. The Blossom robot in three poses (left to right): compressed, gesturing, and fully extended. The soft fabric stretched over rigid and flexible "bones" and "tendons" shows different levels of folds and creases and can emote protectiveness, curiosity, and pride using static poses. Author's own image.

The use of soft, flexible materials has been gaining traction in social robotics. Biologically inspired material approaches are contributing to unique locomotion strategies in soft robotics [30] as well as boosting the expressive and collaborative capacity of social robots [31]. Soft materials are also being used to explore emotional body language and inspire notions of sentience and affect [32].

The Blossom robot developed by Suguitan and Hoffman [33] illustrates the representation of skin folds over bones and tendons discussed above well, as it uses flexible woven and knit fabrics stretched over rigid hardware and is able to communicate a spectrum of potential movement and other static expressions.

As depicted in Fig. 12, the passive folds that appear when the robot's "bones" and "tendons" are compressed (left) or partially compressed (middle) contribute to the demure/sad or curious expression even without movement. Similarly, the smooth and stretched appearance of the knit fabric (right) contribute to its expression of tension or defiance.

6 Conclusion

We presented a proposal for social robot designers to draw inspiration from the practice of sculpture. The proposed approach could imbue socially expressive robots with avenues for movement potential, emotion, and character even when in a static resting pose. We outline three principles which we identified through a curatorial process observing both classical and contemporary Western sculpture: exposure vs. protection of emotional body points, weight distribution, and the compression and extension of soft skin materials.

To demonstrate our proposal, we present a design simulation environment that allows robot designers to link the first two of our principles to specific DoF hierarchies and motor control models. Our simulator demonstrates a pragmatic and concrete way to adopt concepts from a field outside of robotics to aid in the design of robots. Using this approach could aid in the planning and design of robots to boost their communicative capacity in human-robot interaction. Our demonstration shows that a designer could enable highly expressive static poses through the adjustment of a single emotive parameter. In a second demonstration, we illustrate the third principle through its application to a robot that uses fabric stretched over rigid elements. This demonstrates the use of a principle from sculpture on a physically built social robot.

We thus propose that the application of sculptural principles in the design of robotic bodily movement can promote a sense of emotional expression in social robots, aiding readability, lifelikeness and empathy in human-robot collaboration.

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