Dynamic, Situated and Reciprocal: *Unpacking Relationality in Interactive Technology Design and Deployment*

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This article investigates relationality in the design and deployment of interactive technologies, focusing on interactive costuming in performing arts productions. We position relationality as a dynamic, situated, and reciprocal process, and explore how humans relate to and through technology. Our methodological approach follows a post-humanist perspective based on Mediation Theory and Entanglement HCI Theory. Through this framing, we re-evaluate the findings of prior research that is based on a systemic design research study of interactive costuming. To unpack the complex nature of human–technology entanglements, we conceptualize the Adaptability–Responsiveness–Agency (ARA) model to capture the core dynamics that underpin relationality. Based on our analysis, we propose that human–technology relationality can be viewed as driven by these dynamics and unfolding with their context-dependent interactions. We advocate for a relational approach to designing interactive technologies, as it encourages participatory engagement, ethical reflection, and attunement to interrelations.

Keywords **–** More-than-Human-Centered design, Relational Design, Post-humanist Framework, Wearable Computing, Interactive Costumes.

Relevance to Design Practice **–** The research's outcome is the Adaptability–Responsiveness–Agency (ARA) model that unpacks the complexity of relational dynamics in human–technology interactions. It supports a practical understanding of how humans and technologies mutually shape each other and helps designers recognize relation-sensitive design practices.

Citation: Honauer, M., Wilde, D., Hornecker, E., & van Reimsdijk, M. B. (2026). Dynamic, situated and reciprocal: Unpacking relationality in interactive technology design and deployment. *International Journal of Design, 20*(2), 17-30. https://doi.org/10.57698/v20i2.02

Introduction

Digital technologies are an inherent part of the world, closely interwoven with human lives. From a post-humanist perspective, technologies can cause people to relate in certain ways, by shaping how they perceive and interact in the world (Verbeek, 2015). For example, a smartwatch fitness tracker may aim to promote healthy self-perception but may also cause adverse effects, such as frustration or disillusionment, if the constant progress implied by technology based on standardized body norms does not align with the user's situation (Spiel et al., 2018). Furthermore, the technology can be used to mediate social interactions; people use smartwatches to communicate with others and receive notifications and messages. In these instances, we can consider that the people using the technology are *relating* ***through*** *the technology*. In addition to mediating their relations with the self and others, people using smartwatches might also feel connected to the smartwatch as an artifact that makes their lives more enjoyable and convenient (Alaskari et al., 2022). In this instance, we can consider them to be relating **to** the technology.

In this article, we argue that it is important for designers to be aware of people's ability to develop such relations to and through technological products and services, as these entanglements shape technological adoption and innovation. For instance, designers should consider that the feelings of security and trust engendered by technologies impact how people accept technologies (Heath et al., 2019). They should also consider that relationality in design does not apply to usage only. In the article, we explore the broad implications of relationality during the design and deployment of interactive technologies. We unpack how humans relate to and through technologies, and how this relationality may impact the design and deployment process. Complementing participatory approaches that consider the emergence and moderation of relations throughout the design process (Gottlieb, 2022; Poderi et al., 2022), we contribute insights into what characterizes relationality in the design process and the dynamics that underpin it.

We build our investigation on the first author's PhD research (Honauer, 2022), which examines interactive costuming in the performing arts, and in particular, the integration of wearable and e-textile technologies into this highly specialized application field. The thesis offers a preliminary understanding of the relational nature of interactive costumes. That interactive costumes offer innovative ways to engage with expressivity

Received February 24, 2024; **Accepted** May 25, 2026; **Published** August 31, 2026.

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and narration (Pantouvaki, 2014) and require the integration of physical computing skills into costume design (Honauer, 2021) are just two of many aspects that make the relationality of the interactive costume design and deployment processes both intricate and critical to consider. Honauer's research facilitates the practical integration of interactive costuming in the performing arts while maintaining a human-centric focus.

In this article, we revisit the core themes emerging from the original research through a post-humanist lens, thereby complementing this (originally human-centered oriented) research project with a more-than-human-relational perspective. Drawing on research demonstrating how performing-arts practices contribute broadly to fields such as design and HCI (Zhou et al., 2021), we view interactive costuming as a rich site for insights that extend beyond its immediate application field. Given the inherent, intricate, and diverse ways in which relationality plays a role in the domain of interactive costuming, we consider it an excellent foundation for further examining this topic. Doing so allows us to describe the relationality among humans, technologies, and the world in more detail, taking into account that technologies have the capacity to shape how humans relate. We begin by defining relationality. We then provide an overview of types of relations in design and discuss relationality in relation to human–technology entanglements (e.g., one-to-one; one-to-many; human-to-human; human-to-other-entities). We further argue for the relevance of a post-humanist lens for investigating relationality in the design process, particularly in unpacking what determines relationality and the role of non-humans therein. Finally, we present a three-fold model that breaks down the main drivers of human–technology relations while still acknowledging the complexity and context dependence of relationality.

Michaela Honauer is a design researcher and professor at the Technical University of Applied Sciences Nuremberg Georg Simon Ohm. Her work bridges design, human–computer interaction (HCI), social research, and the performing arts. The focus of her research lies in the design of human–technology relationships, particularly in the context of emerging and AI-driven technologies. Her research combines participatory, embodied, and more-than-human-centered design approaches to explore how technology shapes human experiences, social practices, and sustainable futures. Drawing on more than two decades of interdisciplinary practice as a designer, creative technologist, and researcher, she develops innovative methods for inclusive and experiential design. Her work addresses topics such as children's interactions with AI, wearable technologies, human vulnerability, and the empowerment of marginalized groups through technology, contributing to both scholarly discourse and socially engaged innovation.

Danielle Wilde is Professor of Sustainability Transitions at the University of Southern Denmark and Professor of Design for Sustainability at Umeå University, Sweden. She develops participatory Research through Design (pRtD), inviting participants to think through moving, making, doing, gathering, harvesting, preparing, eating, and sharing food. Through these embodied and relational practices, she investigates how new forms of knowledge, participation, and environmental citizenship emerge, expanding what counts as data and how it can be generated, interpreted, and acted upon. Situated at the intersection of design research, environmental humanities, and sustainability transitions, her work explores relationality, multispecies entanglements, and systemic transformation. Through artistic research and transdisciplinary collaboration, she advances relational approaches to design that challenge dominant ways of knowing, valuing, and relating.

Eva Hornecker is a professor in Human-Computer Interaction at the Bauhaus-Universität Weimar. Her work sits at the intersection of technology, design, and the social sciences. Her research focuses on the role of tangibility and embodiment in interactive systems, on user-centered design, and on supporting collaborative application contexts. It has addressed contexts such as learning, elderly care, creative practices, heritage spaces, and museums. Most of her research relies on qualitative methods, creative codesign, as well as research-through-design approaches. She co-founded the ACM Tangible, Embedded and Embodied Interaction (TEI) conference and is a Distinguished Member of the ACM.

M. Birna van Riemsdijk is an associate professor in Intimate Computing in the Human-Media Interaction department at the University of Twente, the Netherlands. Her research mission is to develop design methods and computational models to create intimate technologies that align with personal values and account for personal vulnerabilities, supporting people in their daily lives, thereby fostering a caring and inspiring digital society. For her research on software that takes into account personal norms and values, she was awarded a Vidi personal grant and the Dutch Prize for Research in ICT 2014. She serves on the editorial board of the *Journal of Autonomous Agents and Multiagent Systems* (JAAMAS) and was elected a member (2012-2018) of the board of the *International Foundation for Autonomous Agents and Multiagent Systems* (IFAAMAS). She has served in numerous leadership roles related to Ethics and Responsible AI, for example in the 10-year Hybrid Intelligence NWO gravitation program.

Background

We understand the term 'relationality' as the qualities or conditions of being connected; being in social relation. Relationality is constituted in the interactions humans and non-humans have within the world. Through (inter)acting, one relates to other living and non-living actors; emerging relations are embedded into a larger web of relations (Abbott, 2020). These emerging relations are reciprocal, multi-layered, and dynamic (Selg & Ventsel, 2020); they always have at least two endpoints that are connected and emerge and change over time. Relationality, thus, requires constant negotiation of social relations, and contributes to one's identity (Lejano & Kan, 2022). This is because an individual's existence is shaped by their interactions and experiences. In other words, relationality is not only caused by interactions and experiences but is constituted through them (Selg & Ventsel, 2020). To unpack the reciprocal nature of relations among humans, technologies, and the world, we begin by providing an overview of general types of relations in design.

Types of Relations in Design

To reduce complexity, we initially focus on the dyadic (one-to-one) relations that humans have and propose three main categories of dyadic relations (Figure 1): 1) between humans, 2) between humans, other living entities and assemblages, and 3) between humans and non-human artifacts, technologies, materials and assemblages. These three types of dyadic relations are typically embedded in larger relational networks in which humans share relations with more than one entity; in which other entities are also in relation to each other; and in which human relations are mediated by other human and non-human, living and non-living entities.

The first category, *human–human*, refers to how humans relate to and interact with each other. Human–human relations are built on the behavior, values, and perspectives that individuals carry (Gottlieb, 2022). The complexity and dynamics of such relations depend on many factors, including the extent of shared perspectives and the degree to which moral foundations overlap. As they build relations, people become an inherent part of social and cultural networks that, in turn, define their relationality (Nielsen & Bjerck, 2022). Diverse perspectives and needs come into play in determining relations.

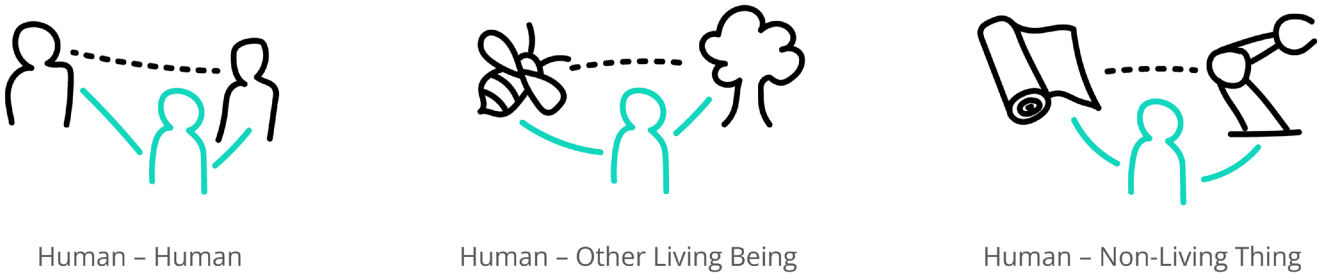

Figure 1. Three potential types of dyadic relations between humans and others.

The second category, *human–other living entities*, concerns relations between humans and entities such as plants (Tomico et al., 2023), animals (Clarke, 2020), mushrooms and other organisms (Tsing, 2015), including those that live on and inside us, arguably constitute us, yet often escape our attention (Wilde & Lenskjold, 2023). While we acknowledge the relevance to design and research practice of this category—the relations that emerge between living entities and humans can profoundly impact life and survival on our planet—our focus in this article is on the first and third category, and how consideration of these relations can contribute to more successful development of technologies.

The final category is *human–non-living thing* relations, which refers to human relations with entities such as non-living materials, artifacts, technologies and assemblages. Materials have dynamic abilities to influence the design and deployment process because of their inherent properties (Bennett, 2010). For instance, plastic is a convenient material for consumer products due to its flexibility and durability, but human relations with plastic are increasingly critical because of its negative impacts on the environment and the health of many organisms, including ourselves. Within the design process, sensory, actuator, and computational qualities can enrich materials used in interaction design (Vallgårda et al., 2016). Beyond the design process, materials can have cultural meaning and determine how end-users perceive and relate to products (Karana et al., 2020). We recognize that people are interconnected with technological artifacts inside their social and cultural networks (Frauenberger, 2019; Giaccardi & Redström, 2020; Kocaballi et al., 2011) and that humans build relations to and through technologies. We characterize direct interactions between humans and technologies as relations *to* technologies, and human interaction with other entities through technology as relating *through* technologies. We elaborate on these technologically mediated relations in the following subsection.

Technology–Mediated Relations

Historically, human-centered theories predominantly attributed a passive role to technologies, understanding humans as the active party emotionally attached to them (Karapanos et al., 2009). This understanding refers to the unidirectional relations humans can have with technologies. More aligned with our own view is the idea that emerging relations between humans and technologies are complex and dynamic. Philosophical approaches ascribe agency to technologies and regard them as mediators of human relations with and engagement with the world (Verbeek, 2015). Instead of regarding technologies as passive tools, we consider them to have the capacity to shape human experiences and existence actively; to influence and transform human practice, action, perception, and interpretation in the world. In this post-phenomenological view, the agency of technology has different notions, including co-construction of realities, mediation of human-world relations, influence on human decision-making and behavior, and carrying morality (Verbeek, 2011). To address this complexity, design approaches to human-technology relations need sensitivity to the agency of technologies (Kocaballi et al., 2011) and ethical concerns (Frauenberger, 2019; Giaccardi & Redström, 2020), to enable design practices for more-than-human-centered worlds (Tomico et al., 2023; Wakkary, 2021) and to foster reflection about emerging relationships (Ghajargar et al., 2018).

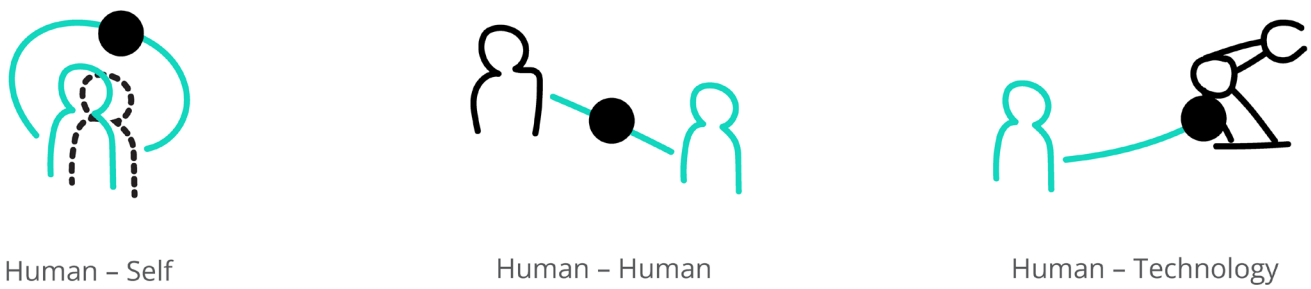

Figure 2. Three types of technologically mediated relations within socio-cultural environments.
The black dots indicate technology mediators. The focus of this schematization is not on the type of technology-based mediation [as in (Ihde, 1990; Verbeek, 2015), for example], but on who or what is being mediated between.

Figure 2 illustrates our understanding of technology-mediated relations. Acknowledging that technologies have the capacity to shape human perception, knowing, being, and acting in the world, we recognize human-technology relations as complex. Technologies can serve as a mediator or a lens between humans, other entities, and their worlds. Taking the example of a smartwatch from the introduction, technologies can mediate how individuals perceive themselves (human–self, Figure 2), their interactions with others (human–human), and their relations to the technology itself (human–technology). Moreover, these relations are woven into socio-cultural environments and contexts. They are not detached from the environments and contexts from which they emerge and within which they exist (human–environments). Rather, they are interconnected. The mediating role of technologies within dynamic socio-cultural environments makes human relations complex and can impact how technologies and environments co-shape the human-sense-making process (Kudina, 2021).

For the remainder of this article, we focus our investigation on relationality in the design and deployment of wearable technologies, using the particular case of interactive costumes in the performing arts. The introduction of e-textiles and wearable technologies into the predefined structures and procedures of performance productions (Holt, 1993) poses challenges to costume design and deployment that impact professional practice. Investigating these impacts and the resulting shifts in existing relations is made possible by considering conventional costume design and deployment (Ingham & Covey, 1992) and recent trends in this professional field (Pantouvaki & McNeil, 2021). We, thus, ground our understanding of human–technology relations on the assumption that technologies and related materials have the capacity to shape human design practices and decisions; and the particularities of the context into which they are introduced must be accounted for as technologies are created, adopted and adapted, if that introduction is to be successful. In the next subsection, we elaborate why we consider a post-humanist lens to be useful to unpack human–technology relationality, and interactive costumes specifically, in ways that can positively impact the development, introduction and integration of technologies.

Applying a Post-Humanist Lens to Relationality in Wearable Technology Processes

Our work builds on extensive evaluation of interactive costume processes, from a human-centered, i.e., not post-humanist, approach (Honauer, 2022). In this article, we apply a post-humanist lens to those findings and suggest that these insights could be relevant for designing other wearable and intimate technologies, similar to how dance-based, post-phenomenological methods have informed human–robot interaction design (Gemeinboeck & Saunders, 2023). The original research (Honauer, 2022) engaged with the question of what facilitates the design and deployment of interactive costumes in the performing arts. The aim was to (a) inform how stakeholders in the performing arts context can leverage the potential of e-textiles and wearable technologies, and (b) to assist interaction designers in optimizing their design and deployment processes. This human-centered stance places humans at the center of interactive costume processes and led the author to frame her findings from an anthropocentric understanding. However, beyond its human-centered scope, the research found that interactive costumes and human stakeholders develop reciprocal relations (Honauer, 2022); interactive costumes both affect and are affected by materials, practices, stakeholders, and timing. This finding means that interactive costumes determine how materials are used, how practices unfold, how stakeholders act, and when events occur. At the same time, their creation and deployment are strongly impacted by available resources, existing practices, stakeholders' expertise, and set timings.

When unpacking these complex interdependencies, *human-centered* approaches reach their limits. Therefore, in this article, we argue for *a more-than-human-centered* approach to understand how both humans and non-humans mutually impact each other—how they relate. More-than-human approaches to design that stem from ideas of post-humanism, decenter the human in the design process to acknowledge the agency of non-human entities (Forlano, 2017). Following the above understandings of technology-mediated relations (see Figure 2), a post-humanist lens enables a more elaborate understanding of the relationality between humans and non-humans without focusing solely on activities, perspectives, benefits, or drawbacks from a human perspective. Rather, a post-humanist lens enables us to think beyond the anthropocentric worldview and account for the relationality that emerges from human co-existence with non-human entities (Ferrando, 2013). The post-human framework, thus, expands upon the original human-centered research project

Our post-humanist framework is built on *Mediation Theory* (Verbeek, 2005, 2015) and *Entanglement HCI Theory* (Frauenberger, 2019). We chose these because they are most relevant to understanding how humans relate to technologies and to providing a practical lens for critically evaluating design practices. Both are grounded in design-oriented HCI and the philosophy of technology, and explicitly connect relationality to the design and use of digital technologies. Other post-humanist ideas are important, but less suited for our purpose. Many remain quite abstract and often focus on understanding non-human entities rather than relational dynamics. For example, the ideas behind *relational ontologies*, as found in Wakkary (2021) and others, emphasize design as a *nomadic practice* and *focus on things*, with the designer playing merely a secondary role. The *alienation framework* (Ianniello et al., 2022) suggests *de-identifying* from our human being and perspective, which is not feasible with our current methods and understandings. Similarly, the theory of vibrant matter (Bennett, 2010) strengthens the *politics of things* and explores non-human agency independently of technological application fields.

More specifically, Mediation Theory and Entanglement HCI Theory allow us to focus on human-technology effects and relational processes, making them particularly well-suited to re-evaluating our themes in the context of interactive wearable technologies. Mediation Theory builds on the ideas that technologies shape human ideas through embodiment and hermeneutic interpretation (Ihde, 1990) and that they influence human actors within their networks (Latour, 2007). Mediation Theory states that technologies are not opposed to humans;

rather, they mediate how humans perceive and act in the world. This theory helps in analyzing the various shapes that mediated relations can take and emphasizes that interacting means relating (Verbeek, 2015). Entanglement HCI Theory builds on Verbeek's Mediation Theory (Verbeek, 2005, 2015) and Latour's Actor-Network Theory (Latour, 2007).

Furthermore, it incorporates the ideas that the autonomy of objects exists independently of human perception (Harman, 2015) and that human–technology entanglements emerge through interaction rather than pre-existing (Barad, 2007). In complement, Entanglement HCI Theory argues that technologies and humans are inseparable and therefore mutually shape each other. This interdependency results in complex entanglements that raise questions about the epistemological and ontological impact technologies can have on humans. Both Mediation Theory and Entanglement HCI Theory are grounded in post-humanist ideas, support our investigation of relationality in design by accounting for relational complexities, and guide ethical reflections on human–technology relations.

Performing Arts Research as a Knowledge Base for Relational Design

Building on this theoretical grounding, we draw on research in the performing arts that has examined how relationality is enacted through embodied encounters between humans and non-human entities. Research in dance and performance shows that technological materials, wearables, and artifacts actively participate in shaping movement, perception, and meaning-making—often through serendipity, ambiguity, and defamiliarization (Wilde et al., 2011) rather than logics driven by problems and solutions (Fdili Alaoui, 2019). In addition, studies of technology-augmented dance demonstrate that introducing interactive or wearable systems can significantly alter production processes and creative decision-making (Latulipe et al., 2011). It has been shown, for example, that interactive costumes impact proprioception and expand movement vocabularies, which can inspire wearable design approaches (Karpashevich et al., 2018). Other examples demonstrate how embodied, practice-based methods have informed relational approaches to human–robot interaction by foregrounding the agencies and constraints of materials and machinic bodies (Gemeinboeck & Saunders, 2023). Two decades of dance and choreography research in HCI further demonstrate that performing arts methodologies contribute transferable conceptual and methodological insights for creativity support and the design of emerging technologies (Zhou et al., 2021). These strands collectively position interactive costuming as a fertile domain for examining how relational dynamics unfold in design processes. This positioning provides us with an appropriate foundation for our post-humanist re-evaluation of the original research project.

Methodological Approach

The research project that serves as our foundation (Honauer, 2022) compares ten case studies through a systemic framing (Luhmann, 2013). This systemic cross-comparison enables a broad study of design processes, institutional structures, and dynamics among the different stakeholders involved in performance productions, and yields eleven core themes that we describe later (Table 1). In particular, the cross-comparison helps identify the relational character of interactive costuming: in summary, interactive costumes affect and are affected by stakeholders, design practices, and deployment opportunities. Their creation and deployment impact numerous stakeholders because they alter typical performance production processes (Ha & Kim, 2014). For instance, costume designers wishing to work with interactive costuming require access to transdisciplinary expertise including interaction design and physical computing (Honauer, 2021) due to e-textile's new materiality (Martinez et al., 2018); and, because of complex technical requirements and enhanced interaction possibilities, performance designers need to engage earlier and more intensely with interactive costumes (Honauer, 2017) to ensure they work in desired ways, and to leverage the new ways to express and narrate that they make available (Pantouvaki, 2014). Interactive costumes are equally dependent on the stakeholders who relate through individual, socially framed preferences and traits (Honauer et al., 2020); success may not be achieved if involved stakeholders are not capable of adjusting to the required interactive costume processes (Honauer & Hornecker, 2015).

We re-evaluate the core themes of the original research (Honauer, 2022) through a post-humanist lens to inform and expand our understanding of relationality in design. The original research did not incorporate a post-humanist lens, as its inclusion was recognized only after the project had concluded. This realization prompted the development of the present work, which revisits the core themes through this perspective. As we will demonstrate, the core themes already contain the main aspects of human-technology relationality in the design and deployment of interactive costumes. This is because relationality (as per our definition) is both caused and constituted by human interactions and experiences with technologies. To demonstrate—and understand the implications of—these findings, we first provide an overview of the eleven core themes of the original research. We then describe how we leverage Mediation Theory and Entanglement HCI Theory, applying our post-humanist lens, to re-evaluate the themes.

Core Themes

The systemic evaluation of the underlying case studies (detailed in Honauer, 2022) is built on the three systemic dimensions of meaning proposed by Luhmann (2013). These dimensions—object, social and time—enable us to analyze interactive costumes' design and deployment from pluralistic perspectives, considering procedural structures and the overall context. Eleven core themes emerged from this systemic evaluation, as summarized in Table 1.

From a human-centric perspective, these themes describe how interactive costumes should be designed and staged to address the needs of human stakeholders. They indicate that costume creators, performers, and other stakeholders must engage with interactive costumes in specific ways to work with them and fully leverage their potential. For instance, themes 02 and 03 elaborate on the specialized knowledge and skills that

creators need; themes 04 and 07 describe performers' relations to costumes' expressive capabilities; and themes 10 and 11 argue that sufficient time with costumes is essential to ensure that a run crew can develop appropriate maintenance practices. It was found that an interactive costume must address the diverse needs of stakeholders if it is to be used successfully. For example, theme 09 elaborates the importance of early positive experiences interacting with a costume, particularly if stakeholders have concerns or little prior knowledge. In the next subsection, we use a post-humanist framing to extract the post-human characteristics and dynamics of the human-technology relations in these eleven core themes.

Analysis Framework: *Operationalizing A Post-humanist Relational Lens*

As discussed above, our post-humanist analysis combines Mediation Theory (Verbeek, 2005, 2015) and Entanglement HCI Theory (Frauenberger, 2019) because these theories embody a range of post-humanist ideas and make them accessible for design research and design-oriented HCI. We began developing our post-humanist lens by extracting the core content of both theories and adding analytical questions accordingly. Both theories emphasize the interwovenness of humans and technologies that results in mutual shaping and co-creation (questions no. 1-3, below). Mediation Theory explains that humans and technologies are co-constitutive rather than separate entities (question no. 3). Entanglement HCI Theory describes the performative entanglement of humans and technologies while acknowledging contextual impact (questions no. 4 and 5). For our analytical framework, both theories offer an inherent understanding of how humans and technologies relate to and through one another. To operationalize our process, we extracted a set of questions concerning the ontological, epistemological, and ethical considerations (questions no. 6 and 7) of these theories. These concern how technologies shape human beings, knowing, and acting in the world, and consider whether the consequences of decision-making are fair and appropriate. Our analysis framework is, thus, based on the following questions:

1. How do technologies shape humans, with regard to…
    a. … human autonomy?
    b. … human meaning- and decision-making?
    c. … knowledge generation?
    d. … experiences?

Table 1. Eleven core themes identified in the original research project (Honauer, 2022)**.**

Label	Theme	Summary
01	**Importance of early interdisciplinary teamwork**	Early interdisciplinary collaboration among costume and interaction designers and electronic engineers to leverage e-textile materials and wearable technologies facilitates new ways of designing performances that are efficiently integrated with the entire production.
02	**Transcending disciplinary boundaries enriches the costume creation process**	Designers engage with standards and norms outside their expertise, and expand their knowledge, skills and tools to be able to create interactive costumes.
03	**Engagement with new practices and materials**	The new expertise of interactive costume creators includes e-textile materials and electronic components, requires physical computing knowledge and engagement with body-centered design approaches to innovate conventional costume design and crafting.
04	**Involvement of stakeholders and consideration of their needs**	Designing and deploying interactive costumes requires collaboration with various stakeholders–such as performers, directors, designers and theater dressers–to address their needs, ensure usability, robustness, functionality and facilitate easy staging and maintenance.
05	**Alignment with other elements of performance design**	As new tools, interactive costumes shape performers' expressivity and audience perception, and thus require careful integration with lighting, sound, and set design to enhance artistic statements while being balanced with the overall performance design and run.
06	**Transfer of creative and technical ownership to costume stakeholders**	Performers, directors and choreographers must understand interactive costumes' functionality to fully utilize the expressive potential (creative ownership) and the run crew needs technical knowledge to be able to maintain and repair them independently (technical ownership).
07	**Dialogicity between performer and costume**	Performing with an interactive costume creates dynamic exchange between performer and costume who ensure together the narrative communication to the audience.
08	**Stakeholder's background and environment influence their appropriation**	The ability of stakeholders to effectively work with interactive costumes depends on their personal background, including their affinity for technology and their environment which both influence their perception of interactive costuming.
09	**Positive experiences foster a positive attitude**	Costume creators, performers and the wardrobe staff need successful interactions with interactive costuming to build confidence, trust and the willingness to continue working with the technology, especially when their skills and knowledge are still developing.
10	**Need for sufficient familiarization time**	From creation over staging to maintenance, interactive costumes require stakeholders to invest time for familiarization to understand and leverage the technology, to ensure its proper use and enhance the performance while addressing safety and functionality concerns.
11	**Extended dress-tech rehearsals are beneficial for the whole production**	Extended dress-tech rehearsals allow all stakeholders to familiarize with the interactive features and the integrated technology–i.e., providing costume creators time to test and improve the costume, enabling performers and designers to explore and balance features, and preparing the run crew for maintenance procedures.

2. How do humans shape technologies?
3. How do humans and technologies mutually shape each other?
4. How do technologies shape networks?
5. How do networks shape technologies?
6. What ethical concerns arise from the human–technology connections?
7. How is ethical responsibility distributed?

We cluster these questions into four categories to operationalize a post-humanist relational lens. The first and second categories embrace how technologies influence A) individuals (based on questions no. 1a–1d and 3) and B) their network (based on questions no. 3 and 4). The next category refers to C) how humans impact technologies (based on questions no. 2, 3, and 5). The last category collects D) ethical concerns and considerations (based on questions no. 6 and 7).

Unpacking Relationality

Here, we examine the eleven core themes (Table 1) according to the four question categories (A-D). Table 2 summarizes this process: Each column aggregates the ways technologies shape humans and the larger network, the ways humans shape technologies, and the ethical concerns that arise from these human–technology relations. We arrive at a rich description of human–technology relations, considering that relationality is constituted by the interactions and experiences within these relations. Crucially, the term 'technologies' is not limited to the final interactive costume applications; it also refers to the components, materials, and processes from which these applications are made. Our insights into these human–technology relations enable us to extract the dynamics that underpin relationality in design and deployment by comparing the changes, opportunities, and challenges that emerge when interactive costume technologies, related materials, and processes are introduced into performance productions.

Characterizing Human-Technology Relations

Our analysis reveals the relations that emerge between interactive costuming and all relevant stakeholders, including creators, users and enablers (see Table 2). These stakeholders relate to and through existing and introduced technologies, materials and processes within a production network when creating and deploying interactive costumes, informed by their pre-existing relations to the context of live performance, its development and staging. Humans and technologies co-constitute their relations. Critically, individuals' relations are not isolated; they affect other individuals, the larger network, and technology. Through the post-humanist lens, we see the ways in which technologies, materials and practices shape and are shaped by humans. Ethical concerns that address additional required resources, redistributed responsibilities, and the potential for new conflicts are also made visible. We unfold these concerns here, across the four question groupings identified above:

Table 2. Assessing the eleven themes of the original research project (Honauer, 2022) **through a post-humanist relational lens.**

Theme	A) How technologies influence individuals	B) How technologies influence the larger network	C) How humans influence technologies	D) Ethical concerns
01 Interdisciplinary teamwork	Change of individual autonomy to design	Mutual understanding, synergies and extended knowledge	Expert collaborations determine successful introduction of new technologies.	More resources required and existing structures are challenged, potential overload and new conflicts, security and privacy concerns.
02 Transcending boundaries			Growing expertise determines successful introduction of new technologies.	
03 New practices/ materials		Establishing new workflows and extending existing knowledge	Adaptation of materials and practices determines successful introduction of new technologies.	
04 Stakeholder involvement	More individual impact on design process and intended usage	Deeper collective involvement in design and deployment processes	Stakeholders impact customization process of technologies.	
05 Performance alignment		Stronger interlinking between departments	Technologies are in service of the overall production.	
06 Ownership transfer	Impact on individual confidence and understanding to design and use technology	Growing expertise in the production network	Taken responsibility and caregiving determine successful introduction of new technologies.	
07 Performer-costume dialogicity		Reduced interdependence between artists and technicians	Degree of reciprocal exchange determines dependence of technology on artist.	Existing structures are challenged, more individual insecurity and potential overload, security and privacy concerns.
08 Stakeholder's background	Confirm, reinforce or contradict prevailing views	Confirm, reinforce or contradict prevailing collaborative views	Human acceptance decides over design and deployment of new technologies.	Undervalue (negative biases) or overvalue (positive biases) of technological innovations.
09 Positive experiences	Gathering new experiences and reducing biases	Gathering new collective experiences and reducing collective biases	Humans' enjoyment decides over design and deployment of new technologies.	Willingness to work with technologies is a prerequisite.
10 Familiarization time	Longer-term investment of individual resources, impact on technological understanding	Longer-term investment of collaborative resources, prolonged workflows and impact on collective technological understanding	Time investment and engagement determine successful introduction of new technologies.	Limited resources and higher demands can cause stress, frustration and conflicts.
11 Dress-tech rehearsals				

A) How technologies influence individuals: Designing interactive costumes requires materials and processing techniques that are uncommon in conventional costume design (theme 03). In particular, the introduction of electronic components and e-textile materials requires costume creators to integrate knowledge from physical computing. It also requires integration of fashion design, which is uncommon in interaction design. Individuals on both sides of the equation—theatre practitioners and interaction designers—expand their expertise and skills through these changes. They transcend their disciplinary boundaries (theme 02) to address new design tasks. Regarding the deployment of interactive costumes, both users and enablers are involved with interactive costume components and prototypes (theme 04) during rehearsals, performance, and maintenance activities (themes 07-11). Each of these examples demonstrates a contrast with standard production processes: If we consider rehearsals, the first dress rehearsal of a production typically takes place just a few days before the premiere. Earlier involvement with a costume enables individuals to gain experience and become familiar with the special attributes of interactive costumes (themes 09 and 10), leading performers to gain greater autonomy in expressing their roles (theme 07). Other stakeholders that may not, typically, be intensely involved in the costume design process likewise gain influence in relation to design decisions (theme 05) and take on new responsibilities (theme 06), e.g., choreographers who align costume effects, capacities, and use requirements with the choreographic work, or wardrobe staff who maintain costumes during the run period.

We conclude from these examples that individuals expand their knowledge and skills, alter existing practices and develop new ones, and take on new responsibilities through newly introduced technologies. They react to changing conditions. Regarding the underlying dynamics, we observe that the effects that technologies have on individuals are driven by (i) regular exchange and communication between individual experts, (ii) their ability to adjust and extend their expert knowledge and practical skills, and (iii) the individual's capacity to design and use newly introduced technologies.

B) How technologies influence the larger network: Expanding from the individual perspective, interactive costuming impacts the whole production network. New technologies establish interdisciplinary collaborations between departments that did not previously work closely together (theme 01). For instance, costume and technology crews need to work together to integrate electronics and plan for appropriate maintenance and repair processes. Design and deployment responsibilities are thus redistributed across the larger network (theme 06). Further, the time and resources a production invests increase with interactive costuming due to newly introduced materials and practices (theme 03) and prolonged rehearsals (theme 11). For example, a planned costume with integrated lighting features requires continuous experimentation among set, performance, and costume design to exploit the full potential of possible costume effects. The production network ultimately becomes more interlinked when aligning interactive costumes with the overall performance (theme 05).

We conclude from these examples that networks of individual experts, production structures and activities get more entangled because of the interdisciplinary nature of interactive technology design, development, and usage. Regarding the underlying dynamics, we observe that the resulting network–technology entanglements are caused by (i) more communication and collaborative work within the network, (ii) a growing mutual understanding between different disciplines, and (iii) the felt collective responsibility to design and use newly introduced technologies. We observe for networks—as it also holds for individuals—that technology exerts influence on humans within the human capacities and limits.

C) How humans influence technologies: Just as newly introduced technologies shape how humans relate to and through them on an individual and a network level, humans also shape the technologies. For instance, a costume designer who does not know how to integrate electronic components into garments will not be able to work with e-textiles and wearable computing appropriately. If they have acquired the necessary knowledge about the new materials and practices (theme 03), they can customize interactive costume solutions. Further, we found that an individual's personal and social background determines how they approach interactive costuming (theme 08). For instance, fear or respect for technologies worn on the body prevents performers from experimenting with an interactive costume. As a result, the costume's full potential might not be exploited. Depending on how individuals experience the introduced technologies (theme 09) and how familiar they become with them over time (theme 10), individuals become more open and willing to work with interactive costuming (theme 06). If humans accept and, ideally, enjoy newly introduced technologies, they will not only make use of them, but find or create new opportunities to integrate them into performing arts productions. The technologies and materials can, thus, be placed in the service of humans and will be leveraged to enhance performances—i.e., shaped—as and how humans are ready and prepared for them.

We conclude from these examples that individuals and networks shape the design and deployment of new technologies based on the readiness and willingness of human stakeholders. Available knowledge, adapted practices, and open-minded contexts on the part of these stakeholders all provide the circumstances within which interactive technologies can develop, offer their full qualities, and adjust to the stakeholders' needs. Regarding the underlying dynamics, we observe that technologies' relations to humans are driven by (i) their initiating and attention-catching potential, (ii) their perceived usefulness in alignment with human needs, knowledges and practices, and (iii) the extent to which they are customizable for specific purposes. We observe that humans proactively determine the trajectory of technology; humans shape it; and technology can only change within the boundaries set by humans.

D) Ethical concerns and considerations: From an ethical perspective, in the case of interactive costumes, newly introduced technologies require humans' investment if they are to succeed. More time, and often budget, is needed to design and deploy interactive costuming (themes 10 and 11); more experimentation,

knowledge and interpersonal exchange is needed to make informed design decisions. These requirements may challenge the tight planning and strictly organized infrastructure of typical performance productions and create potential for conflict. For example, conflicts could emerge between departments when responsibilities to create and maintain interactive costumes are shifted from the costume department to become a shared responsibility between costume and technical crew (theme 01). Conflicts can also emerge for individuals who may feel overwhelmed by new tasks and be unprepared to acquire new knowledge and practices (theme 03), e.g., a tailor with no prior experience with electronics. Individuals may feel pressured to educate themselves in subjects that they consider irrelevant to their profession. Production managers and interactive costume creators must be aware of these challenges if they hope to tackle them and benefit from the opportunities that accompany interactive costumes, such as enhanced expressivity and narration (theme 07). There are also safety and privacy concerns with the introduction of new technologies that need to be addressed carefully throughout the entire production chain. Challenges such as low-level electrocution and other issues specific to costume attributes require vigilance both when engaging with such technologies for the first time and as people become familiar, thereby increasing the risk of complacency. Further, if introduced technologies collect and store data from the wearer or their environment, individual rights and data protection must be ensured throughout the design and use process.

We conclude from these considerations that the introduction of new technologies carries potential for inner (intrapersonal) and outer (interpersonal and human–material) conflicts due to the newly required resources that impact relations, i.e., knowledge, practices, and collaborations. The potentially emerging conflicts put successful human–technology relations at risk and require thoughtful guidance throughout the design and deployment process. These ethical and safety considerations add to the existing well-documented and commonly attended-to considerations.

Next, we outline the recurring, mutually influencing dynamics in more detail.

Dynamics Underlying Human–Technology Relations

Our analysis of the 11 core themes through a post-humanist relational lens (see Table 2) affords a richer understanding of how humans and technologies are entangled in the design and deployment of wearable technology. Both sides influence each other, while humans remain the dominant force, and technologies remain in humans' service. There seems to be a tendency for their relations to be extractive rather than mutually constitutive. Still, technologies encourage humans to self-determine how they comply with the changing conditions introduced by new technology; humans actively shape the technology and determine how it evolves based on human choices and actions. Together they co-constitute their relation. The emerging relations between human and non-human actors are *dynamic, situated, and reciprocal.* Human-technology relations are interdependent. The continuous back-and-forth of their interactions, experiences, and dependencies determines the nature of their (inter)relations. However, what exactly makes this 'continuous back and forth' happen? What enables their interactions, mutual experiences and dependencies? To understand what constitutes 'the qualities or conditions of being in relation', as per our definition of relationality, we identify three types of dynamics necessary to understand relationality. These are adaptability, responsiveness, and agency (ARA, Figure 3).

1) Adaptability refers to the capacity to adjust, modify, or change one's behavior, strategy, or (re)actions towards the other side of a relation. It is connected to an entity's ability to be flexible, resilient and responsive to interventions and changes. We found that adaptable individuals gain new knowledge both through input from others and experimenting with materials (e.g., themes 01 and 02); and that they adjust their practices to design and deploy interactive costuming (e.g., themes 03 and 11). In complement, we found that interactive costume technologies are considered to be in the service of, and exist to fulfill, both human (e.g., the choreographer/director/designer's and performer's) and non-human (the performance's) requirements (e.g., theme 05); and that they need to comply with these human and non-human needs and get modified accordingly (e.g., theme 04). In brief, we observe that both sides adapt to each other while the human remains superior.

2) Responsiveness refers to the ability to have and share inner and outer reactions to stimuli or changes. It is connected to the directed attention and inherent willingness of a relating entity to respond to the other side(s). We found that individuals communicate and exchange more with others (e.g., themes 01 and 04) than they did without the introduced technologies, and that people's personal and social backgrounds impact how relevant or aesthetic they deem interactive costuming (theme 08). Further, if interactive costumes are perceived as meaningful, i.e., if they respond to human (and the performance's) needs (themes 07 and 09), they have the greatest chance to be successfully produced and staged. In brief, we observe that both sides respond to each other, with technologies serving humans.

3) Agency refers to the capacity to act, make choices and exert influence. It is connected to the opportunities and circumstances that make acting, choosing and influencing possible. We found that when individuals contribute to the design and deployment of interactive costumes, they actively participate (e.g., themes 06 and 10) by experimenting with the related technologies, exploring new practices and developing new knowledge. At the same time, the technologies affect how humans design and deploy interactive costuming by offering their capacities, characteristics, and expressive features (e.g., themes 05 and 07). In brief, we observe that both sides have agency to drive change depending on their inherent qualities and capabilities, the outer context, and situational possibilities.

As represented in Figure 3, the three central dynamics of Adaptability, Responsiveness, and Agency (ARA) are closely connected and constitute the relational interplay between entities, to dynamically determine how relations unfold, within the situated contexts of action:

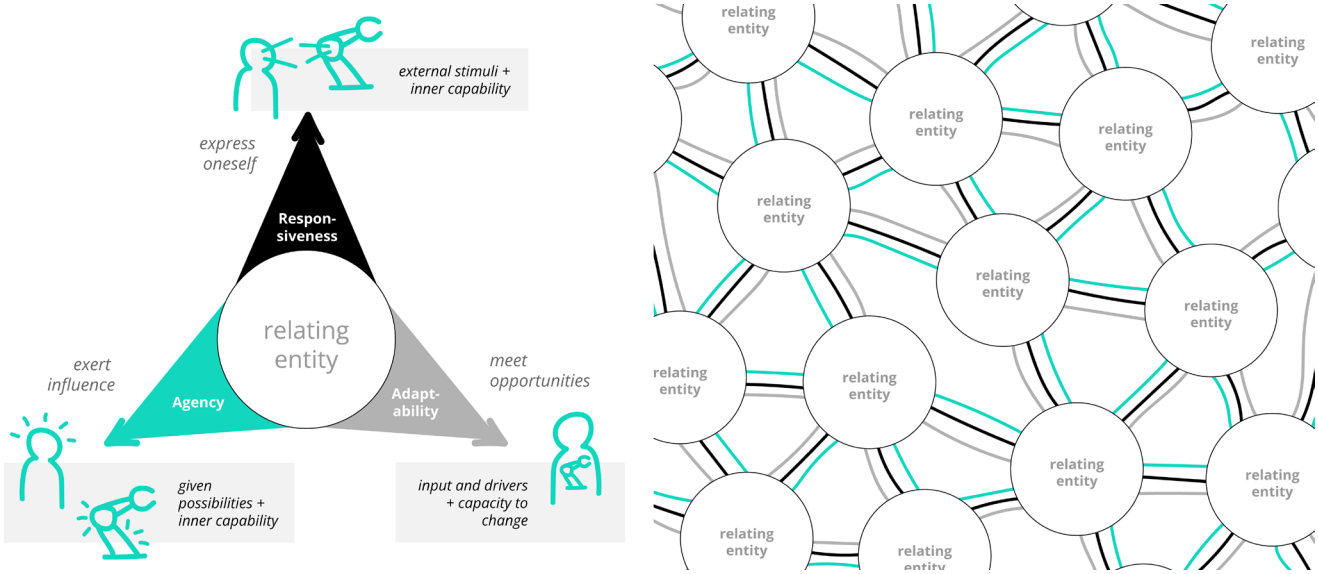

Figure 3. Three central dynamics drive relationality–Adaptability, Responsiveness and Agency (ARA)**.** Left: Individual level of a relating entity—be they human or non-human. Their relational dynamics are displayed in green (Agency), black (Responsiveness), and grey (Adaptability). Right: Systemic level of many relating entities interconnected through relational dynamics displayed through lines colored in green (Agency), black (Responsiveness), and grey (Adaptability).

Adaptability refers to how related entities alter their states and actions to approach others. It relates to the resilience of attitudes, knowledge, and behavior in response to new contexts and circumstances. Through flexible adjustments to reach shared goals, adaptability drives compromise, acknowledging and accounting for differences in collaboration among entities. Adaptability requires exchange between entities, the success of which is determined by responsiveness.

Responsiveness constitutes how an entity reacts to what it perceives from others. It changes over time depending on the entity's adaptability. What constitutes responsiveness for humans is an inner emotional or rational reply, often biased or framed, that they can show to the outer world. For finished interactive technologies, responsiveness could manifest, for example, in making transparent which data is being processed (e.g., mapping movement to light). By regularly disclosing positions and states, responsiveness drives negotiation and communication between entities. Responsiveness makes further visible how much influence an entity exerts on someone or something and, thus, how much agency they have.

Agency constitutes the ability of entities to act and to impact others. Both inner (e.g., cognition) and outer (e.g., material and structural) conditions determine agency. In essence, agency encompasses the capacity to initiate actions, make decisions, and control the outcome. Through taking actions and opportunities to achieve change, agency drives autonomy and intentionality in the power structures between entities. Critically, Adaptability can increase one's agency (e.g., gaining necessary knowledge), and vice versa: adaptability can result from another's agency (e.g., knowledge from a master class).

To enable meaningful and sustainable relations to unfold over time, the three ARA dynamics need to be balanced flexibly yet reliably. It matters how humans relate to and through technologies. Interactive technologies can only be leveraged to the extent that their stakeholders understand and make use of them. Similarly, interactive technologies only succeed if they align with and fulfill stakeholders' needs. We, therefore, posit that an understanding of the rich dynamics of situated human–technology relations is integral to the success of technology design and deployment; they combine human and non-human perspectives; both sides need to be considered to have agency, be responsive, and be adaptable.

Designing with Relational Dynamics

The Adaptability–Responsiveness–Agency (ARA) model breaks down the underlying relational dynamics involved in the design and deployment of interactive technologies. It captures the reciprocal, situational nature of relations shaped by human and non-human entities. We propose that understanding these dynamics can facilitate interactive design and deployment processes fit for context-specific integration.

Limitations and Scope

Our analysis is grounded in interactive costuming within the performing arts, which affords rich, embodied cases but constrains the types of relational dynamics we can observe and may limit transferability. The ARA model emerges from a retrospective re-interpretation and has not yet been empirically evaluated beyond this case; future work should examine its robustness across other domains and settings. The selected case is mainly based on extractive relations between humans and technologies, which limits the possibility of foregrounding alternative, more participatory, and non-anthropocentric configurations. Finally, the post-humanist lens was applied after the original study concluded; as such, the analysis we contribute is retrospective rather than concurrent, and subsequent studies should incorporate this lens from the outset of empirical inquiry.

The Role and Responsibility of Designers

Beyond creating applications, products, and services, designers shape how stakeholders influence the design and deployment of interactive technologies. Research has found that this concerns both human and non-human stakeholders (Poderi et al., 2022). While orchestrating and framing stakeholder participation through their design approach, designers ultimately influence stakeholder relations. They therefore require relational expertise to recognize and respond to stakeholders' offers and influences as they become collaborators (Dindler & Iversen, 2014). Being aware of and thoughtfully balancing the relational dynamics represented in the ARA model may support designers in carrying out their social and ethical responsibilities while exercising their expertise in the design discipline. We posit that the ARA model, thus, supports the materialization of morality, or what Verbeek describes as 'doing ethics by other means' (Verbeek, 2006). By using the ARA model, designers can acknowledge the goals, needs, and desires of involved stakeholders by actively engaging them in design decisions, thereby giving stakeholders agency. They can facilitate stakeholders' responsiveness through organizing shared spaces, activities, and possibilities for exchange. Designers can share knowledge and best practices that ease and inspire individuals' approaches to other entities, thus encouraging stakeholder adaptability. Consequently, the ARA model can be useful for designers to become more aware of and attuned to the situational and relational dynamics among stakeholders participating in the design and deployment process. This awareness is known as 'relational sensitivity' and likewise addresses self-reflection on how the designer enacts their position and relationality within the network (Gottlieb, 2022). We posit that the ARA model provides insights into the dynamics underlying the unfolding relations a designer depends on and must be sensitive to.

The ARA model, as we describe it here, highlights that relationality in design is situated, dynamic, and reciprocal. This suggests that effective design practice should prioritize context-awareness flexibility and openness to support relationality among all stakeholders. Design processes that encourage pluralistic engagement, continuous exchange, and iterative learning loops create opportunities to experiment with materials, explore unusual design strategies, and facilitate communication among stakeholders. Understanding the ARA dynamics makes clear that designers are not only creating artifacts or services; they are shaping relations between humans, technologies, and systems. This understanding has implications for the design outcome beyond the design and deployment process. It suggests that designers must constantly reflect on how their work shifts power dynamics (e.g., do parental control features put children under surveillance or protection?); how it creates dependencies (e.g., the Apple eco-system allows easy connection between Apple devices and services but is often difficult to access from other hardware/software platforms); and shapes not only interactions but also identities (e.g., feedback mechanisms in social media determine a person's recognition among their peers). When designing with the ARA dynamics in mind, designers can consider how technologies both respond to and shape human needs, values, and biases; ideally, it better equips them to design for meaningful responsiveness. Furthermore, designers will ideally ensure that humans retain agency in their relationships with/through technologies while still acknowledging and revealing technologies' active role. Designers using the model will, ideally, shift away from designing static products or predefined interactions and services and instead begin designing for a kind of co-evolution in which various stakeholders co-adapt, are mutually responsive, and share a well-balanced distribution of agency.

From Interactive Costuming to Other Design Contexts

The ARA model has been derived from the re-evaluation of a research project on the design and deployment of interactive costuming from a post-humanist perspective. Although interactive costuming is a highly specialized niche application field and the ARA model has been derived from such a data set, it can serve as inspiration for other application fields where wearable and intimate technologies mediate interactions (Fdili Alaoui, 2019). The ARA model offers a lens through which we can examine relational dynamics in digital technologies beyond interactive costuming. Relational entanglements are central to many other fields, such as smart wearables (Nelson et al., 2024), healthcare technologies (Chen et al., 2024), mental well-being (Tost et al., 2024), and urban design (Forlano, 2016). Each domain presents varying degrees of how relationships unfold, which situational conditions are relevant, and how humans and technologies shape each other. For instance, fitness trackers should adapt to support individual goals instead of reinforcing normative standardizations of a healthy body (Spiel, 2019); assistive technologies should make transparent and embrace biases and breakdowns instead of tackling them as something undesirable (Forlano, 2023); and the (re-)design of urban environments would benefit from accounting on multi-species perspectives to arrive at more sustainable solutions (Clarke, 2020). The context of use is crucial, and the transferability of the ARA model depends on the situated nature of potential and intended interactions. To leverage the ARA model in design research and practice and to design for relationality, interdisciplinary teams are well-served by focusing on mapping relational dynamics early in the design process and continually reconsidering their initial mapping throughout the design and deployment process.

The ARA model further provides a lens for examining the role of AI in human–technology entanglements, particularly as AI systems transition from interactive tools to co-actors in decision-making and other forms of interaction (Bradshaw et al., 2009). Unlike conventional digital interfaces and services, AI can adapt, interpret, and respond to human users (Zhao et al., 2022). AI's (re)actions, however, are grounded in data-driven learning processes and inferences that differ from human cognition and emotion (van Rooij et al., 2024). Researchers therefore emphasize that AI systems should be designed to be collaborative, adaptive, responsible, and explainable (Akata et al., 2020), to ensure that healthy and sustainable relations can unfold between humans and AI. Considering this, we envision that ARA may be a useful tool for guiding the design and development of AI-based applications

and devices, complementing approaches such as coactive design for human-robot teamwork (Johnson et al., 2014). Our model makes transparent how possible core dynamics driving relations are distributed among the involved entities and to what extent the entities hold individual capacities to relate. It can support an understanding of how agency is distributed between humans and technology (e.g., reinforcing mutual accountability); facilitate the design of transparent communication behavior (e.g., asking for needs or explaining the 'black box'); and prepare for adaptive processes on both sides (e.g., training for expert users or alignment with social values). Future research may address these ideas and investigate the extent to which the ARA model is valid and relevant to human–AI relationality.

Conclusion

This article has explored the complex nature of relationality in the design and deployment of interactive technologies, with a focus on interactive costuming in the performing arts. Through a post-humanist lens, we have unpacked how humans relate to and through technology, recognizing that relationality is a dynamic, situated, and reciprocal process shaped by the interplay of humans and technology. Our investigation has revealed that interactive costuming does not merely serve as a tool for human expression but actively mediates and co-constitutes design processes, individuals' interactions, and their broader networks.

To conceptualize these complex entanglements, we introduced the Adaptability–Responsiveness–Agency (ARA) model. It aims to capture the core dynamics underpinning relationality in design: *Adaptability* is the capability to meet opportunities, *Responsiveness* is the ability to express oneself, and *Agency* is the capacity to exert influence. These dynamics pertain to all related entities and are determined by the interplay of their internal qualities and external opportunities; they unfold through context-dependent interactions.

By framing relationality as a dynamic, situated, and reciprocal process, we highlight the necessity for transdisciplinary design approaches that embrace flexibility, participatory engagement, and ethical responsibility. The ARA model encourages an understanding of how humans and technologies mutually shape each other and offers a lens for designers to navigate the ethical and practical implications of their work. Future research should explore the transferability of the ARA model to other design contexts and application fields to refine how it supports understanding and the fostering of sustainable and meaningful human–technology relations.

As technologies continue to entangle with everyday life, design practices must evolve to account for relational complexity and the vibrancy of non-human actors. In this regard, our research contributes to a growing discourse on post-humanist perspectives in design and research. Following a relational approach to design allows design researchers and practitioners to attune to interdependencies, become more context-sensitive, and intentionally shape the multifaceted ways in which humans and technologies co-exist, collaborate, and evolve.

Acknowledgments

The authors sincerely thank all individuals who contributed to the studies included in this meta-study. Whether through participation, collaboration, expertise, reflection, design, or other forms of engagement, their contributions have been invaluable to this work.

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