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Symbiosis: Regrounding interactive fashion design with posthumanist thinking

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ABSTRACT

The advancement of technology is profoundly reshaping human living environments, work modes, cognitive patterns, and even identity constructs. The boundaries between human and non-human, machine and organism, virtual and physical, are increasingly blurred and interwoven. As a philosophical and social theory, posthumanism reveals that technology has evolved beyond a passive tool to become an active, agentic co-participant. This paper adopts a posthumanist perspective to explore how technology can achieve deep integration with human subjectivity within a framework of symbiosis, tracing the evolution of interactive fashion from linear control to bidirectional adaptation and, ultimately, to collaborative co-agency. Building on this, the study proposes five core mechanisms of symbiotic interactive fashion design: distributed agency, collective sensing and intelligence, decentralised adaptive decision-making, proactive and emergent interactions, and eco-ethical design orientation. Together, these mechanisms aim to construct a more intelligent, decentralized, and sustainable strategic framework for interactive fashion, offering methodological and ethical guidance for future fashion practices.

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Posthumanism, interactive fashion, human–computer interaction, decentralization, multi-agent symbiosis, proactive interaction

1. Introduction

Interactive fashion is undergoing a critical stage of transformation from instrumentality to symbiosis. In the past, the interaction model based on human-centrism regarded technology as a response mechanism for service subjects and emphasized the user's control over the system. However, with the rapid development of artificial intelligence and wearable computing, interactive systems are gradually showing perception, autonomy and

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situational adaptability. The mediation and subjectivity of technology are strengthened. In this scenario, the human-based standard for measuring the scale of all things shows dual limitations in theory and practice (Woods and Dekker 2000). It is challenging for traditional design paradigms to explain and guide the evolution of new interaction modes fully.

Therefore, we need to jump out of the human-centred design framework and rethink human nature as a generative existence in multiple relationships (Cruickshank and Trivedi 2017; Xu and Ge 2024). The subject is no longer an isolated individual but is continuously constructed through dynamic interactions with technology, the environment, others, and non-human intelligence (Coskun et al. 2022; Gherardi 2025; Ramiller 2016). The boundary between self and others becomes blurred, and a complex perceptual network is formed between humans and multiple ecological and technological entities (Dinerstein 2006; Fiorani 2021; Pedroso-Roussado et al. 2025; Rajcic and McCormack 2023). In this symbiotic structure, design serves as a practical mechanism for coordinating the relationship between numerous intelligent entities, promoting the formation of a decentralised, cross-border, and embedded way of existence.

As a system of thought that rethinks the relationship between humans, technology, non-human life, and the ecological environment, posthumanism expands the traditional cognitive paradigm of identity, existence, and social significance, emphasising the collaborative status of multiple intelligences and life forms in the co-construction process (Behzad et al. 2022; Homewood et al. 2021; Onishi 2011). This theory offers an interdisciplinary approach to understanding human intentions, ecological evolution, and living conditions in the context of technological intervention. It advocates abandoning the opposition between anthropocentrism and anti-humanism and instead building a non-hierarchical (Mara and Hawk 2009), cross-species symbiotic logic (Van der Zaag 2016), providing a theoretical fulcrum and guiding practical development direction for reshaping interactive fashion (Bignall and Braidotti 2019; Vanska 2018).

Symbiosis is an extension of posthumanism at the practical level. Symbiosis originally refers to the survival and cooperation relationship between different species based on mutual benefit (Frank 1995; Martin and Schwab 2012; Su'arez 2018). When applied to human-computer interaction and sociotechnical systems, it is extended to coexistence, interdependence and dynamic coordination among multiple subjects (Inga et al. 2023; Leaver 2011; Mammadov, Asgarov, and Mammadova 2025). Especially in the field of interactive fashion (Dinu and Bodiciu 2023), symbiosis is no longer just an ecological metaphor but provides an interactive mode that transcends control and master-slave logic.

This study aims to explore how interactive fashion can achieve the construction of a new symbiotic relationship through technological media in the context of multi-subject co-construction, with posthumanism as the

theoretical framework. We focus on the key role of non-human factors such as technology, algorithms, and virtual agents in shaping fashion forms and experiences and attempt to provide a more complex, multi-dimensional, and contextualized strategy system for interactive fashion design, guiding designers to re-examine the role of technology in constructing perception, meaning, and behaviour, and expand the practical path of human-machine co-creation. Furthermore, as technology acquires greater agency, traditional ethical frameworks that focus solely on human-to-human relationships are no longer sufficient to address emerging challenges. The key question thus shifts to how to establish sustainable symbiotic relationships with these non-human intelligent subjects. Therefore, this study explores how to achieve a deep integration of functional support and emotional care through a perception-driven, context-adaptive interactive fashion system. It adopts a perspective that transcendence technological ethics and social equity. This notion of 'transcendence' does not imply abandoning ethics and fairness, but rather extends the scope of care from human society to a hybrid ecological network composed of humans, technologies, the environment, and other subjects. This perspective highlights the potential of intelligent design to promote design democratisation, cultural diversity, and the empowerment of vulnerable groups. For example, developing barrier-free clothing interfaces and context-aware technologies for people with physical disabilities or the elderly can enhance their participation in the fashion system.

In summary, this work provides the following key contributions:

- Propose an interactive fashion design framework that integrates the perspective of posthumanism, reconstructs the relationship between human and non-human subjects, and emphasizes the design logic of multi-subject symbiosis, technology co-construction and identity flow.
- Explore perception-driven, adaptive response mechanisms and multimodal interaction, propose collaborative design strategies, and expand the technical boundaries for interactive fashion.
- From the perspective of technological ethics and social equality, pay attention to the accessibility and expression rights of marginalized groups in the innovative fashion system and call for the construction of a more inclusive, diverse and decentralized design ecosystem.

2. The evolution of posthumanism in technology and design

2.1. The transformation of technical identity

The transformation of technological identity is mainly based on changes in cultural values and social relations rather than the existence of technology itself (Lemonnier 2013). Our discussion of technological identity stems from its focus on its central role in shaping social structure, individual identity,

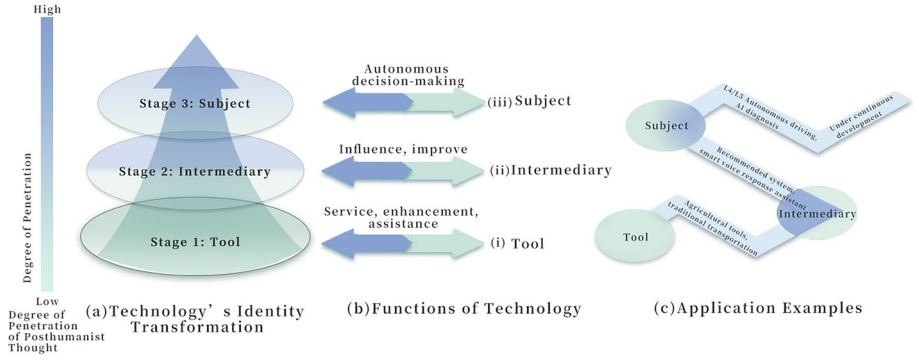

Figure 1. The transformation of technology identities, functions and applications.

future development direction, and its connection with posthumanist philosophical thought, involving three layers of technological identity, as depicted in Figure 1. This discussion not only consists of the evolution of technology but also reveals the continuous updating of human understanding of technology, as well as the changes in the roles and mutual relationships between technology and humans in society.

2.1.1. Technology as tool

In the early stage of technological development, its primary functions lay in empowerment and optimization, simplifying human labor and daily life through instrumental intervention, during which technology was still regarded as an extension of the human subject, as shown in Figure 1 (i). At this stage, technology largely occupied what Heidegger refers to as the ready-to-hand mode, in which its tool-like existence is absorbed bodily and integrated into everyday practice (McDaniel 2013). Examples such as prosthetic limbs, magnifying lenses, cochlear implants, transportation devices, and agricultural machinery all participate in human action by enhancing bodily capabilities or perceptual functions (Lunceford 2012; Rutsky 2018). However, when technology becomes alienated in operation, malfunctions, or is brought into reflective attention, it shifts from being ready-to-hand to present-at-hand, compelling the user to move from practical engagement toward an awareness of the technological object itself, becoming conscious again of its material characteristics and its relationship to the body (McDaniel 2013).

2.1.2. Technology as intermediary

After the evolution of technology entered the intermediary stage, its function surpassed the traditional tool attribute, as shown in Figure 1 (ii), and began to intervene in human perception, cognition, and behavioural mechanisms, redefining the boundaries of the body and the structure of experience. During this period, posthumanist ideas gradually emerged, and technology

no longer passively served humans but showed synergy in forming cognitive environments, reshaping behavioural paths, and shaping emotional experiences (Floridi, 2014). The embedding of technology renders the human body no longer a closed, natural entity but a dynamic interface that interacts with external systems, such as virtual platforms and perception networks. For example, the brain-computer interface headset developed by Neurable can recognize intentions based on brain electrical activity, allowing users to interact with the digital interface without gestures (Jantz, Molnar, and Alcaide 2017). Teslasuit simulates real physical touch in a VR environment through a full-body tactile feedback system, making the body embodied in the virtual experience (Caserman, Krug, and Gobel 2021).

2.1.3. Technology as subject

When technology moves from an intermediary to a leading role, as shown in Figure 1 (iii), it is no longer just an auxiliary tool or intermediary but an entity or virtual entity with autonomy (Bukatman 1993), creativity, perception, and even decision-making and consciousness, participating in guiding information flow, behavioural mechanisms, and meaning construction (Hayles 2000; Onishi 2011). For example, based on emotion perception, VR can automatically adjust the atmosphere of psychotherapy virtual scenes (Chen et al. 2024), intelligent agents can actively guide teaching (Zhang et al. 2024), and L4 or L5 autonomous driving can be enhanced (Kavas-Torris et al. 2023). This evolution challenges the traditional anthropocentric perspective. Humans are no longer the only cognitive centre (Wu 2020). From a posthuman perspective, these technological changes reveal that the relationship between humans and technology is no longer one-way or antagonistic but instead mutually shaping. In some cases, technology can even exist and function independently of humans. It is worth noting that the identity of technology is not fixed but depends on the specific context. Specifically, it depends on its embedding mode, interaction mechanism and the perceptual structure involved. In different scenarios, the same technology may appear as a tool, an intermediary, or a collaborative subject, reflecting the multiplicity and dynamism of technological agency.

2.2. Embodiment and disembodiment

Embodiment advocates that cognition and consciousness are not abstract functions that operate independently of the body but rather dynamic processes embedded in the interaction between the specific body and its environment (Wolfe, 2010). This position rejects Cartesian mind-body dualism and emphasizes the core role of the body in perception (MacCormack 2016; Mehta 2011), action and identity construction. Furthermore, posthumanism views embodiment as a variable and expandable structure, where the body

transitions from a biological entity to a sensory complex, highlighting the potential for cross-species and cross-media interactions (Forlano 2017). For example, Spider Dress, a wearable device designed based on sensing and mechanical feedback, enables the dynamic expansion of the body boundary by sensing the distance of surrounding people and actively making defensive movements (Toussaint 2018). Heartthrob Dress and Breathing Dress reflect the wearer's emotional state in real-time through changes in LED lights, highlighting the phenomenon of co-construction of body and technology, and clothing becomes an extension of embodied cognition rather than an appendage (Xia, et al. 2011).

In contrast, disembodiment refers to the digital reconstruction of body functions and the immaterial translation of perceptual mechanisms (Erbentraut 2024). In this context, the body is no longer the sole carrier of the subject's existence but becomes an information node that can be virtualised, copied, and replaced (Du Toit 2024). Technological development has enabled language, consciousness, and memory to be processed in a programmable manner. The human subject has gradually broken away from the boundaries of the flesh and turned to algorithmic existence (Leonzi et al. 2024), such as virtual images, AI personalities, and data continuity (Yaghoobian 2025). At present, the expression of disembodiment in interactive fashion mainly relies on immersive media, such as AR and VR, which enables fashion expression to break away from the attachment to material clothes or fabrics and transition into a cross-platform, dematerialised identity interface. Auroboros (Kim et al. 2024), DressX (Mallon 2024) and The Fabricant (Sarmakari 2023) and other digital fashion brands or platforms. This type of design transcends the physical boundaries of the body, emphasising the plasticity of the digital body and the fluidity of virtual identity (Baek et al. 2022; Choufan 2022; Kim and Kim 2015). This trend not only expands the way existence is expressed but also triggers a rethinking of individual continuity, ethical boundaries, and control.

Although the two paths are different, embodiment and disembodiment present a synergistic tension in posthumanism. On the one hand, the simulation model on which disembodiment is generated is deeply rooted in embodied experience. On the other hand, embodiment is also reorganized and alienated in the penetration of digital technology. Therefore, based on posthumanist theory, this subject view, which is detached from human-centeredness and cross-border integration, becomes a key theoretical path to understanding the complex relationship between technology, the body, and consciousness.

2.3. Decentralization design

The traditional design is mostly centred on rational subjects or users, and it presupposes that humans have dominance and control (Boy 2017; Cooley

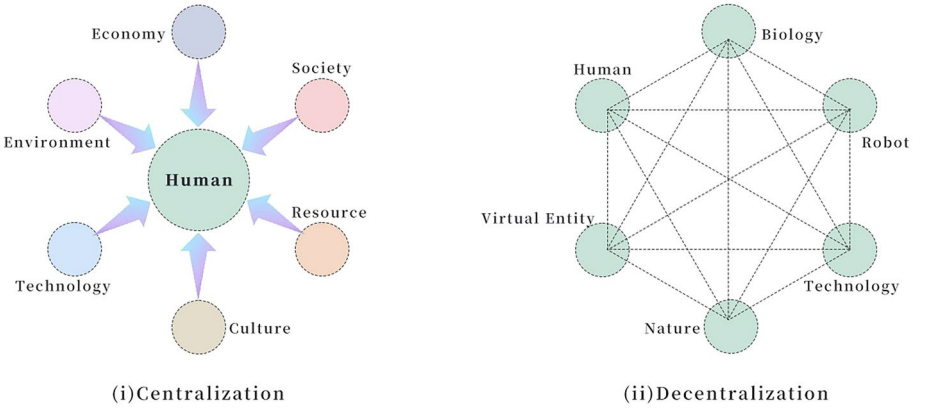

Figure 2. Comparison between centralization and decentralization.

2000), as shown in Figure 2(i). Posthumanism advocates that animals, plants, technical systems or material environments are regarded as collaborators with agency and perception, encourages decentralized design, incorporates non-human elements into the scope of design subjects, no longer seeks a single goal or central intention, and emphasizes the collaboration and relational generation of multiple subjects (Gane 2006; Nicenboim et al. 2025b), as shown in Figure 2(ii). This concept resonates with Escobar's design-for-the-pluriverse perspective, opposing the reinforcement of a singular worldview and supporting the construction of alternative worlds by acknowledging the agency of nonhuman actors (Escobar 2018). At the same time, Puig de la Bellacasa's ethics of care provides practical guidance for decentralized design, emphasizing attention to the often-invisible labor that sustains symbiotic relationships and framing design as a process of establishing responsible, long-term reciprocal relationships with both human and nonhuman actors (P'erez de Arenaza, 2023).

Notably, the decentralized design advocated by posthumanism is methodologically aligned with deconstructionist thought in fashion. Since the work of Rei Kawakubo and Martin Margiela, deconstructive practice has disrupted the modernist myth of clothing as a complete product by exposing structures, dismantling forms, and emphasizing temporality, thereby weakening the authoritative relationship between designer and garment (Loscialpo, et al. 2011). Symbiotic interactive fashion further extends this deconstructive logic from the aesthetic level to the ontological level. It not only deconstructs the form of clothing but also destabilises the central position of the human subject.

In design practice, this concept is reflected in many forms. For example, Electric Corset project demonstrates how bodily expression emerges through distributed agency between garment, material, and wearer (Kettley et al. 2019). BioCouture positions non-human media (such as bacteria) as

participants in the design system and advocates the establishment of a distributed and decentralized agency between species and design prototypes (Langella 2024; Paz et al. 2024; Wood, Verran, and Redfern 2023). Ecological design emphasizes the overall health of the system. (Naveh 2000; Shu-Yang, Freedman, and Cote 2004). AI and algorithm-assisted design introduce creative collaboration of technical subjects (Xu and Ge 2024). Blockchain or collaborative platforms realize open co-creation without central control (Abbate, Codini, and Aquilani 2019; Hu, Rong, and Tay 2025; Manceski and Nechkoska 2023). These practices break the traditional binary relationship from designer to user, making design a dynamic process of co-construction between humans and non-humans. Therefore, decentralized design is not only a methodological innovation but also represents a shift in epistemology and ethics, pushing design practice towards a broader ecological coexistence framework.

3. Related work

3.1. Interactive fashion design

Traditional fashion has emphasized the visual presentation of form and material, focusing on aesthetic appearance and stylistic expression. Within this context, clothing is regarded as a static object to be viewed, lacking the capacity for active engagement. However, with the increasing integration of technology such as sensors, artificial intelligence, and wearable devices, fashion has gradually acquired human-like perceptual capabilities, thereby transcending the limitations of purely visual expression. Garments are evolving into dynamic systems capable of sensing and responding to both environmental stimuli and human presence. These perceptual abilities encompass multiple sensory dimensions, including olfactory, visual, auditory, haptic and tactile feedback (Ruckdashel, Venkataraman, and Park 2021), and even extend to a degree of cognitive responsiveness (Lu, Chen, and Sui 2016), reflecting distinct characteristics of anthropomorphic intelligence, as illustrated in Figure

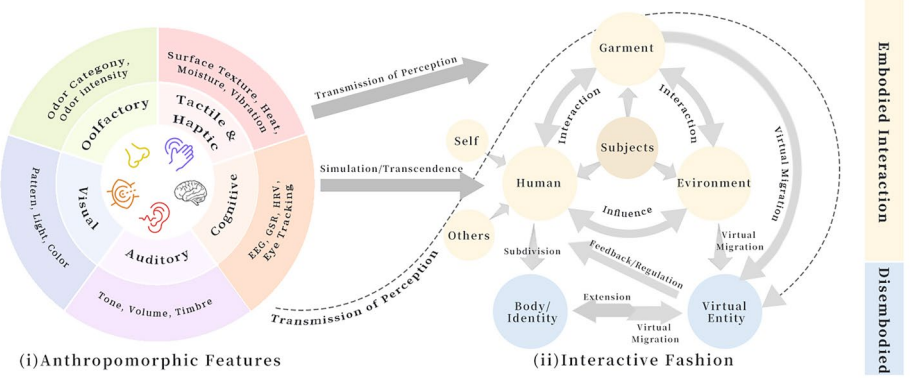

Figure 3. Interactive fashion design in the posthumanist perspective.

Table 1. Symbiotic interactive fashion design projects.

Project	Interaction mechanism	Symbiosis Dimension	Technological medium
Smoke Dress (Wipprecht and Casas 2013)	Emits smoke when sensing proximity	Human-environment	Proximity sensors + Smoke emission system
BioLogic (Wang et al. 2017)	Opens flaps in response to body humidity *via* bacteria	Human-microbe	Living bio-material (Bacillus subtilis)
Caress of the Gaze (Farahi 2016)	Fabric reacts dynamically to viewer's gaze	Human-observer	Eye-tracking + 3D-printed soft materials
Adrenaline Dress (Segran 2023)	Sensors detect stress, triggers structural expansion	Emotion-body-machine	Biometric sensors + Actuators
Pseudomorphs (Hess 2011)	Liquid ink drips triggered by motion/algorithm	Body-material-system	Ink system + Motion input
Soundwave Dress (Cass 2016)	Voice input visualized as LED light patterns	Body-sound-visual	Microphones + LEDs
Breathing Wings (Fritsch et al. 2025)	Responds to user's breathing rhythm in real time	Human-transition space	Respiratory sensors + Biofeedback visualization system

3 (i). On this basis, interactive fashion has emerged as an intelligent system that integrates perception and responsive mechanisms. It is capable of real-time detection of users' physiological signals, such as heart rate, body temperature, and movement, while also perceiving external environmental factors, including light intensity, ambient sound, and social proximity (Sohn 2011). The interaction mechanisms have evolved from simple stimulus-response patterns to systems endowed with decision-making, prediction, and contextual adaptability. Advanced forms of interactive fashion can anticipate user behaviour, recognize emotional states, and provide coordinated feedback and situational adjustments. This facilitates a deeper emotional and behavioural co-construction between the wearer and garment (Hassib et al. 2016; Paterson 2017). Fashion is no longer merely worn but emerges as an intelligent symbiotic entity with cognitive and interactive capabilities.

As shown in Figure 3 (ii), this evolution has prompted us to divide interactive fashion into two typical paths: embodied interactive fashion and disembodied interactive fashion. The former emphasizes the body as the core of information input and meaning production. Taking the items in Table 1 as an example, the closed-loop interaction between people, garments, and the environment is strengthened through mechanisms such as physiological signal sensing, motion capture, and behavioural feedback, reflecting sensory interactivity driven by embodied cognition (Foglia and Wilson 2013; Heinzel and Hinestroza 2020; Xiong et al., 2025). Regarding the latter, researchers generally focus on the role of technologies such as VR, AR, and avatars in building extensible identity systems (Lau and Ki 2021; Teng 2019). Such technologies promote interaction and flow between virtual and reality by breaking through the limitations of the physical body, emphasising the plasticity of individual identity, the portability between platforms, and the immersion of virtual experiences (Belk 2013; Kao 2019). For example, Prakash et al.

explored how a virtual try-on system based on gesture recognition can enhance user engagement and realism, responding to the limitations of clothing fit and tactile interaction in online shopping (Prakash et al. 2024). Burnstine's research findings suggest that fashion AI agents are transforming the design and creative ideation process by facilitating human-machine collaboration. (Burnstine 2025). Related research further suggests that users are more likely to enter a flow state in physical interaction scenarios, such as virtual try-on, which is a highly immersive and intrinsically motivated cognitive experience. This state significantly enhances the user's sense of participation, pleasure, and willingness to make decisions, especially in commercial scenarios such as virtual fitting and personalised recommendations (Lin et al. 2025; Park, Ko, and Do 2023). It can be seen that the interaction mechanism is not only a channel for perception but also a key variable that affects user behaviour and psychological feedback and constitutes the core of constructing human-computer relationships.

3.2. Symbiotic design strategy

To address the increasingly complex design challenges of human-computer interaction (HCI), researchers have developed a multi-level, interdisciplinary symbiotic design framework from the perspectives of technological evolution and cognitive interaction over the past few years (KU, 2025; Walden and Makhortykh, [2024]; Okamoto and Yamakawa, [n. d.]). In the early days, Licklider (1960) first proposed the concept of human-computer symbiosis, emphasising that humans are responsible for setting goals and formulating hypotheses, while computers process complex data to assist human decision-making, laying the foundation for the basic model of human-computer collaboration (Institute of Radio Engineers 1960). With the development of artificial intelligence, contemporary symbiotic systems have surpassed the initial auxiliary model and are gradually moving towards the stage of technical symbiosis, characterised by autonomous judgment, data generation, and intervention capabilities (Carnevale et al. 2023). In this regard, Carnevale et al. proposed a hierarchical symbiotic model, covering from the biological or material level to task execution and multi-task compound, and then to the cognitive autonomy level of intelligent subjects, systematically expanding the scope of application of symbiotic design (Carnevale, Lombardi, and Lisi 2024).

At the operational level, Inga et al. constructed an analytical framework for evaluating the function and operability of symbiotic systems from four dimensions: task, interactivity, performance and user experience (Inga et al. 2023). At the higher level of culture and ethics, researchers gradually realized that human-computer symbiotic design is not only a functional collaboration issue but also involves the deep embedding of cultural concepts and value systems. For example, Xu et al. proposed the idea of cultural symbiosis, highlighting

the isomorphism between the current human-computer interaction mode and the relationship structure between humans and nature (Xu and Ge 2024). The concept of human-centrism is implicitly replicated in the technical system, which limits the actual realization of the symbiotic relationship.

To promote future-oriented technology governance, Marra et al. proposed a procedural decision-making model, advocating for the development of a symbiotic AI system that is both ethically acceptable and legally compliant, as well as widely adaptable (Marra et al. 2024). At the same time, related models have been utilised in intelligent manufacturing (such as Industry 5.0) to facilitate a more balanced information flow and knowledge collaboration among humans, machines, and the environment (Peruzzini, Prati, and Pellicciari 2024). These studies indicate that the symbiotic design strategy is gradually shifting from a human-centred interaction logic to a posthumanist paradigm based on multi-agent collaboration, realizing the co-evolution of technical systems at the functional, cognitive, ethical, and ecological levels.

Regarding the evolution of symbiotic design strategies in the field of fashion design, Bodiciu's research and our work have similar theoretical orientations. Bodiciu expanded the conceptual dimension of symbiosis in the field of fashion, arguing that the relationship between body and clothing is not a master-slave relationship but a continuous 'coming-together' state, emphasizing the dynamic co-construction of the two in the generation of experience and meaning (Dinu and Bodiciu 2023). In contrast, the symbiotic interactive fashion design strategy we proposed starts from the actual design of HCI and intelligent fashion systems and is committed to transforming this philosophical perspective into specific design principles and operational paths and promoting the systematic symbiosis between people, garment, environment, and technology by building a perception-feedback closed loop, realizing real-time co-creation, and data-driven collaborative decision-making.

4. Symbiotic interactive fashion strategies

In the strategic construction of symbiotic interactive fashion design, we advocate starting from the reconstruction of the subject structure, expanding to the collaboration mechanism, decision-making mode, behavioural logic and value orientation layer by layer, and forming a systematic strategic path, as shown in Figure 4. First, emphasize the initiative of multiple subjects and give humans, non-humans and technology a joint role. Secondly, build a collective perception and intelligent collaboration mechanism to enhance perception sharing through sensing and computing. Furthermore, adopt a decentralised dynamic decision-making model to facilitate adaptive adjustments and feedback among the various system elements. At the same time, design an active, interactive system with prediction and learning capabilities to promote the deep integration of people, garments, and the environment.

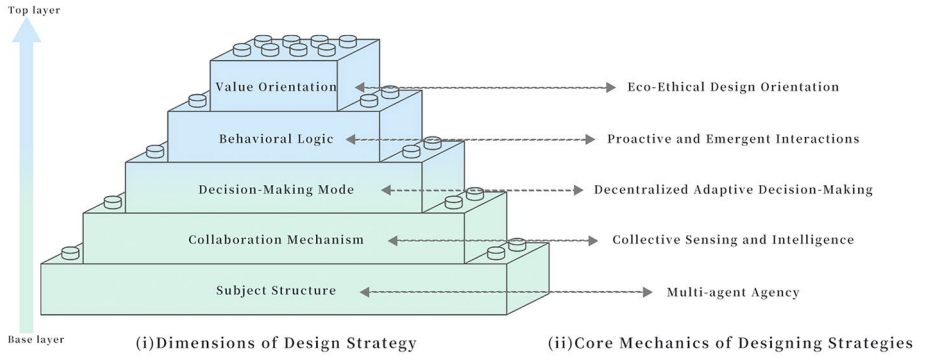

Figure 4. Symbiotic interactive fashion design strategies.

Finally, advocate for ecological ethical awareness in top-level guidance to encourage the evolution of the fashion system towards a diverse, inclusive, and sustainable symbiotic ecology.

4.1. Multi-agent agency

Distributed agency is a philosophical stance that emphasises decentralisation. In symbiotic interactive fashion design, it aims to break through the traditional anthropocentric paradigm, build a collaborative intelligent system with multi-source input and cross-border response, and systematically give equal agency to both human and non-human elements, recognising their independent perception and feedback mechanisms. The design perspective is expanded from the needs of a single subject to the complex interaction between multiple subjects, thereby enhancing the design's complexity and adaptability. This approach enables an efficient response to environmental changes and diversified needs while also strengthening the innovation ability and flexibility of the fashion system. A representative example is the Karma Chameleon project, which creates an all-fiber textile that harvests, stores, and converts human-generated energy within the fibers. Agency is distributed among body movement, material structures, energy conversion, and fiber-level actuators, collectively driving the textile's dynamic responses (Wainwright 2016). This strategy also helps shift the focus of design from a single product function to the construction of a multi-level relationship network, encompassing the interaction modes between people and technology, technology and nature, and people and people, thereby promoting the deep integration and continuous symbiotic evolution of technology, humans, and the natural world.

4.2. Collective sensing and intelligence

Collective sensing and intelligence are key mechanisms of the symbiotic interactive fashion system. It aims to establish a perception network that

encompasses people, clothing, and the environment through the deep integration of sensor networks and intelligent computing technologies, promoting information sharing and collaborative judgment among multiple subjects. This mechanism emphasises multi-source input and intelligent processing of perception, breaking the previous human-centred, information-dominated model so that humans, non-human entities, and technical systems have relatively balanced initiative in perception and response. Through sensors that collect environmental status, user behaviour, and body data, and by combining algorithmic processing and pattern recognition, the system can achieve higher-dimensional perception capabilities and situational understanding, thereby supporting real-time, accurate, and dynamic behavioural feedback.

On this basis, the collective sensing and intelligent collaboration mechanism prioritises the mutual coupling and feedback relationship between the various elements of the system rather than relying on linear control logic or a one-way command chain. As shown in Figure 5, the mechanism depends on the integration of six key data streams, including environmental perception, body movements, physiological signals, cognitive intentions, language texts, and external events. These multimodal data not only constitute the basis of the system's perception capabilities but also drive the generation, adjustment and optimization of system behaviours through real-time interconnection and dynamic feedback between them. In other words, the realization of collective intelligence stems from the collaborative processing of these heterogeneous data in a distributed structure, which enables the system to have adaptability and evolution capabilities for complex situations. For example, MIThril wearable computing platform exemplifies collective sensing and intelligence by integrating a distributed network of environmental, bodily, and behavioral sensors with multiple computing cores to enable

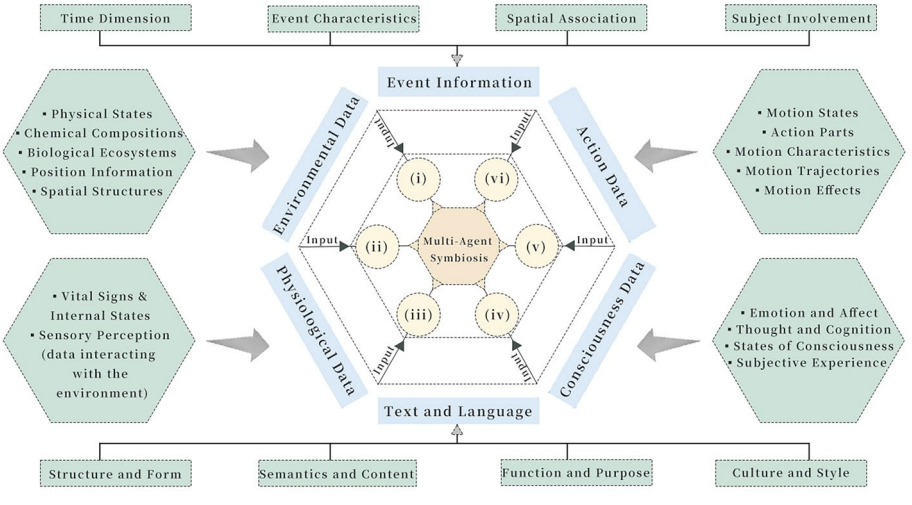

Figure 5. Intelligent symbiosis: capability sharing in a decentralized structure.

context-aware, collaborative decision-making beyond human-centric control (Ashok and Agrawal 2003).

In this framework, the role of designers has also changed: they are no longer the controllers or command makers of a single product but the architects of data flows and interaction paths. They are responsible for planning the information relationships, data priorities and behavioural feedback logic between various subjects, thereby building perception-decision-feedback closed loop with both flexibility and collaboration.

4.3. Decentralized adaptive decision-making

Posthumanism advocates for breaking the centralised structure of power and control and building a multi-autonomous decision-making ecology. In the symbiotic interactive fashion system, the decentralised dynamic decision-making mechanism not only redistributes power but also systematically reconstructs transparency, flexibility, and participation in the decision-making process. With the help of technologies such as artificial intelligence and machine learning, the system can achieve autonomous judgment and local optimisation among multiple nodes, thereby forming a real-time feedback loop based on rules and data. This mechanism is different from multi-agent agency. Its focus is not on the granting of subject power but on how multiple nodes dynamically coordinate in a nonlinear way and collaborate to complete the decision-making process. At the same time, it differs from collective sensing and intelligence. It not only stays at the level of perception and cognition but also converts the perception results into executable strategies and behavioural paths. In this mechanism, users are no longer passive response objects. Still, they are deeply involved in the system's decision-making logic as nodes, thereby realising distributed autonomy between people, technology, and the environment. This structured, decentralised processing method significantly improves the adaptability, anti-interference ability, and response speed of the system, allowing the interactive fashion system to maintain stability, efficiency, and continuous evolution in highly complex and dynamic real-life situations.

As shown in Table 2, to implement the above mechanism, the system's technology architecture can be divided into five core modules, forming a dynamic, interactive, closed loop with self-organisation and learning capabilities. In the first part, the multimodal perception unit efficiently collects both human and non-human data through embedded sensors, enabling synchronous monitoring of individual status and environmental changes. In the second part, as the active body in the system, the innovative material can provide visual or morphological feedback based on real-time data and exhibit closed-loop characteristics of perception and response. In the third part, the algorithm system integrates artificial intelligence models that can learn based

Table 2. System framework: technological implementation of multi-agent interaction.

Module	Technological components	Agentive behavior
Sensing Unit	Embedded sensors (e.g. heart rate,GSR, motion, proximity, light, temperature)	Captures human and environmental states, triggering system changes proactively
Smart Materials	Thermochromic fibers, photoresponsive fabrics, bio-reactive textiles	Respond to environmental or physiological data, enabling material-led visual/kinetic feedback
Algorithmic Core	AI models (e.g. style recognition, behavioral prediction), biofeedback, mapping algorithms	Learn user patterns, predict intentions, and autonomously generate interaction outputs
Feedback Mechanisms	LEDs, vibration motors, AR displays. shape-changing structures	Deliver visual, tactile, or virtual feedback, reconfiguring perception and experience
Co-creation Platform	User interfaces, algorithm fine-tuning tools, collaborative design modules	Enables users, algorithms, and other stakeholders to participate in shared decision-making

on user behaviour trajectories and generate feedback strategies with situational adaptability. In the fourth part, the multimodal feedback mechanism combines media such as LEDs, vibration motors, AR interfaces, and variable structures to provide visualisation and multisensory output, realising rich interactive expressions. In the final part, the co-creation platform facilitates the collaborative participation of users and algorithms, ensuring that the design adjustment process is open and flexible.

4.4. Proactive and emergent interactions

From the perspective of posthumanism, proactive interaction systems, as one of the core strategies of symbiotic interactive fashion design, embody the key characteristics of technical systems such as predictability, self-learning ability and emergence. Unlike traditional reactive interaction systems that only passively respond to user input or environmental stimuli, proactive interaction systems can actively identify potential behaviour patterns, predict user needs, and adjust system status in advance, thereby achieving a more accurate and forward-looking interactive experience. By integrating technologies such as machine learning, contextual awareness, and emotion recognition, the system can dynamically deduce users' potential needs based on their historical behaviour data, environmental variables, and physiological signals, even if these needs have not yet been explicitly expressed.

As shown in Figure 6, taking emotion-aware interaction as an example, proactive interaction systems use multimodal data collection, such as facial expressions, voice intonation and skin galvanic response, to identify users'emotional states in real-time, and automatically adjust the color, texture or shape of clothing accordingly. For example, when the system detects that the user is in a low mood, it will actively switch to a color or material with a soothing effect to provide emotional support. In this process, the design intention goes beyond merely implementing a technical loop of emotion recognition

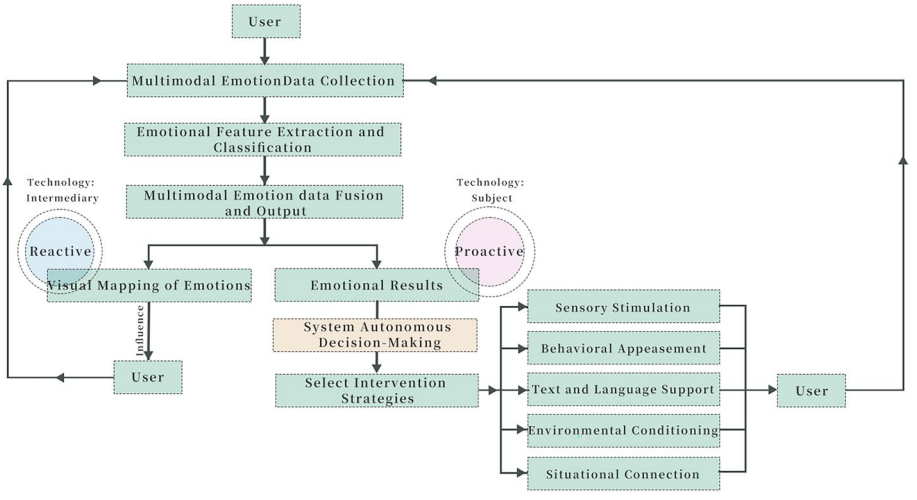

Figure 6. The interactive system process of emotional reactivity and proactivity.

and color adjustment, it seeks to create the metaphor of a 'second skin' through the interactive fashion system. The system not only senses the wearer's psychological fluctuations but also responds through dynamic feedback, establishing an emotional-level interaction with the wearer. Similar systems demonstrate the potential of smart healthcare in scenarios such as telemedicine, hospitals, and communities (Mensah et al. 2025). In contrast, traditional reactive systems usually rely on the user's manual settings to make adjustments. The advantage of this type of active interaction is its higher time sensitivity and adaptability, which enable it to respond promptly to changes in the user's internal state.

Furthermore, this proactive interaction system demonstrates the capacity for self-evolution and structural reorganization through emergent mechanisms. The system no longer depends on preset linear interaction paths; instead, through machine learning and collaborative adaptation within continuous multi-subject feedback loops, it achieves nonlinear expansion and dynamic optimization of design logic and functional performance, enabling continuous adaptation to complex and changing environments and user needs. In summary, it intertwines technological intelligence with the designer's sensuous intent. The former provides predictive and dynamic adjustment capabilities, while the latter imbues the interaction with humanistic warmth and aesthetic depth. Their synergy is not only a functional enhancement but also embodies a poetic experiment of multi-subject relationships co-constructed by designers, wearers, and the technological system, marking the key distinction of proactive interactive fashion from mere technological display. In the future, seamlessly integrating similar proactive interactive fashion systems into everyday wear will be both a challenge and a huge opportunity to realize their value.

4.5. Eco-ethical design orientation

As the top-level guiding principle of symbiotic interactive fashion design, the core of ecological ethics orientation is to introduce the philosophical thinking of posthumanism to redefine the subject and the ecosystem, emphasizing that design must go beyond the single human interest and comprehensively consider the coexistence and mutual influence of humans, non-human life forms and the environment (Biggs, Bardzell, and Bardzell 2021). This design consciousness requires designers to assess the protection of the ecological environment consistently, the sustainable use of resources, and respect for cultural diversity in technological innovation and fashion expression. It not only focuses on the life cycle management of fashion products but also examines the long-term impact of design behaviour on social and natural systems, promoting design that shifts from consumption-driven to responsibility-driven and advocates for ecological balance and social equity (Chen, Cachat, and Pschetz 2025).

In practical applications, an ecological ethics orientation prompts design strategies that focus on the selection of environmentally friendly materials, the development of low-carbon production processes, and the establishment of a recycling system, thereby fundamentally reducing the burden of the fashion industry on the ecosystem (Nicenboim et al. 2025a). At the same time, the design process emphasises tolerance of cultural diversity, respects the values and lifestyles of different groups, and avoids the imposition of single values, thereby forming a diverse and open design ecosystem. Through this top-level ethical framework, symbiotic interactive fashion design can build a paradigm that maintains a balance between technological progress and ecological sustainability.

From the perspective of technological ethics and social equality, the ecological ethics orientation pays special attention to the accessibility and expression rights of marginalized groups in the innovative fashion system. With the penetration of technology and algorithms in fashion, design should not acquiesce in the reconstruction of social relations by technology but should actively intervene in the practice of technological justice. Symbiotic interactive fashion design, from the perspective of ecological ethics, is committed to eliminating exclusion caused by technological barriers, economic differences, or social discrimination so that marginalised individuals, such as those with disabilities, the elderly, and individuals with non-mainstream gender identities, can participate equally and have the right to express their bodies, identities, and cultures. This is not only an extension of sustainability but also a design embodiment of systemic social justice.

On a deeper level, the ecological ethics orientation reflects the decentralised thought of posthumanism, which does not place humans at the centre of the ecosystem but instead views them as one of the symbiotic nodes. It encourages design to focus on the health and vitality of the system as a

whole. It emphasises that the design results should promote harmonious interaction between humans and nature, as well as between humans and technology, rather than one-way domination or consumption. Therefore, ecological ethical design is not only a technical means of environmental protection but also an ethical commitment and cultural awareness.

5. Conclusion

Starting from the complexity of the interactive fashion system, this paper proposes a set of design strategy paths with symbiosis as the core. This strategy emphasises the structural transformation from a single subject to multi-subject collaboration, advocating for humans, non-humans, and intelligentsystems to have initiative in design to achieve collective sharing of perception, cognition, and decision-making. At the same time, this paper proposes a decentralised decision-making mechanism and a proactive, interactive system to break the traditional control and control relationship between humans and machines, promoting a more flexible and reciprocal interactive mode. Finally, we emphasise the embedding of ecological ethics into the design value orientation and encourage a shift from technology-driven to more systematic thinking, integrating cultural and environmental considerations. This strategy not only responds to the re-examination of the relationship between technology, body, and environment in the context of posthumanism but also provides a theoretical basis and practical guidance for building an inclusive, dynamic, and decentralised future smart fashion ecology.

Author contributions

CRediT: **Jiayu Zhu**: Conceptualization, Investigation, Methodology, Visualization, Writing – original draft; **Yi Wang**: Validation, Writing – review & editing; **Xingxing Zou**: Funding acquisition, Project administration, Supervision, Validation, Writing – review & editing.

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