Smiles Summon the Warmth of Spring: A Framework for Thermal and Affective Design Grounded in Classical Chinese Poetry

Feng Feng
fefe@itu.dk
IT University of Copenhagen
Copenhagen, Denmark

Dan Bennett
db15237@bristol.ac.uk
University of Bristol
Bristol, UK

Elisa D. Mekler
elme@itu.dk
IT University of Copenhagen
Copenhagen, Denmark

Figure 1: The eight Chinese characters representing different thermal states, illustrated with photographs (see Section 4). Calligraphy by first author.

ABSTRACT

Thermal-affective experience is a growing topic in Human-Computer Interaction. However, research linking thermal and affective experience in technology use has not moved beyond attempts to establish broad, sweeping associations, such as between warmth and positive affect. One of the obstacles to progression is the need for frameworks and vocabularies that describe and conceptualise the richness of thermal perception and affective experience. To help conceptualise associations between thermal perception and affective experience we turn to *Cí poetry*, a form of classical Chinese literature rich with evocative descriptions of embodied, environmentally situated, first-person experience. We conducted a lexical analysis to identify thermal-affective associations, and propose a design framework addressing thermal design. We demonstrate the value of this framework via analysis of existing thermal design exemplars.

CCS CONCEPTS

• **Human-centered computing → HCI theory, concepts and models**; **Interaction design theory, concepts and paradigms**.

KEYWORDS

Thermal, affect, emotion, translation, cross-cultural, lexicon, design, framework, multisensory

ACM Reference Format:
Feng Feng, Dan Bennett, and Elisa D. Mekler. 2024. Smiles Summon the Warmth of Spring: A Framework for Thermal and Affective Design Grounded in Classical Chinese Poetry. In *Designing Interactive Systems Conference (DIS '24), July 01–05, 2024, IT University of Copenhagen, Denmark.* ACM, New York, NY, USA, 18 pages. https://doi.org/10.1145/3643834.3661620

DIS '24, July 01–05, 2024, IT University of Copenhagen, Denmark

ACM ISBN 979-8-4007-0583-0/24/07
https://doi.org/10.1145/3643834.3661620

1 INTRODUCTION

In HCI there is a growing interest in thermal interaction design. Researchers have increasingly turned to thermal technologies to augment haptic interactions, for instance, to convey affective information [93], create immersive and aesthetic multisensory experiences [15, 39], and support affective regulation [19] or mindful body awareness [44].

A challenge in further developing this line of research is that much bodily experience remains in the background of awareness, and as such can be difficult for users and designers to articulate in language [73, p. 206]. HCI researchers have noted similar difficulties in other areas of interaction design [66, 69, 92]. In particular, the haptics community has long recognised the need to develop vocabularies that account for the intricacies of haptic experience [69, p. 101]. Work in this area has demonstrated how haptic design language can facilitate the conceptualisation of rich experiences and help connect these experiences to design parameters [66, 77]. To date, however, no such efforts have addressed thermal experience. In existing work, vocabulary linking thermal experience to design is sparse and mostly restricted to simple terms like "warm"/"hot", "cold"/"cool" and "neutral" [e.g. 28, 56, 94]. This narrow vocabulary makes it difficult to articulate and discuss the nuances of thermal experiences, which could inform a wider range of designs. It also impedes the identification of thermal cues that can support meaningful affective experiences.

Responding to the difficulty of describing sensory and affective experience, researchers have turned to literature [e.g. 23, 59], art [e.g. 2, 82], and different language cultures [e.g. 54, 55, 80], as sources of sensory metaphors and vocabulary for analysis. Likewise, in recent years HCI researchers investigating bodily play have looked beyond the English-speaking world to introduce lexicons from Danish [60], German and Chinese [65].

We suggest that, as HCI seeks to better understand sensory-affective experience in technology design, it should continue along this path: engaging with cultures and languages outside the English-speaking world. With this in mind, we turned to a form of classical Chinese literature renowned for its rich descriptions of embodied human experience [42, 102]: 词: Cí poetry [9, 70]. We drew on this literature as a store of lexicons and knowledge about thermal experience. Specifically, we identified a corpus of Cí poetry containing descriptions of thermal and affective experience, then subjected this to lexical analysis. This allowed us to extract vocabulary and identify patterns in life-situated, and emotionally resonant descriptions of thermal experience (Section 4). Building on this analysis, we propose a framework for the design of thermal interaction and thermal-affective experience (Section 5). We illustrate the framework's usefulness via discussion of selected design projects (Section 6), demonstrating how the framework supports the analysis of research and design, and how it helps generate new research directions. Finally, we end with some reflections on the generative contribution of translation, and the potential to expand the framework in future, via the analysis of other literary texts (Section 7).

2 BACKGROUND

In the following, we provide an overview of research on thermal-affective interaction and cross-cultural lexical analysis in HCI, before introducing Cí Poetry.

2.1 Thermal Interaction

Over the years, interactive technologies have expanded beyond sight and sound to further enrich the possibilities of interactive experience: incorporating haptics [e.g., 29], scent [e.g., 61], and, increasingly in the last decade, thermal aspects of experience. Design researchers have, for example, explored the potential of *thermal haptics* – physical heat and cold delivered via direct contact with the body – to convey emotion [28, 49], create perceptual illusions in VR [53], and support body-awareness and self-care [19, 44]. However, the role of thermal cues in technology is not limited to haptics. HCI researchers have also considered imagery of fire or ice to convey temperature, atmosphere, affect, and the affordances of an object [16], as well as investigated the potential to convey thermal illusions via scents [15]. We refer to all these as instances of *thermal interaction.*

To date, there has been relatively little work on wider aspects of thermal interaction, with most research focusing on thermal haptics. Lin et al., for example, examined conceptual metaphors and sensory correspondences in interaction with thermal haptics (e.g., "warm is soft" and "cool is hard") [51]. Meanwhile, Lee and Lim investigated heat as a modality to support interpersonal connection during remote communication, via a wrist-worn thermal device [49]. Later work in HCI has focused on laboratory experiments, using the forced choice paradigm from sensory psychology, to understand how thermal stimuli can be used to convey emotions [e.g., 56, 98, 99]. Beyond lab studies, thermal cues have been used to convey information and experience in a variety of applications, including navigation [e.g., 105], affective augmentation of text and voice messages [e.g., 28], emotional regulation [e.g., 94] and meditation [e.g., 19].

While these works attest to the promise of leveraging thermal cues in interaction design, there is still a lack of integrative and theoretical work on thermal interaction. This contrasts with haptic design where researchers have developed vocabularies to help communicate and describe experience [66, 69], describe real world issues in the design process for haptics [76], and translate between engineering parameters and experiential descriptions [77].

Specifically, several obstacles remain for effectively communicating and analysing thermal interaction and thermal-affective experience. First, there is ambiguity in results mapping specific thermal ranges to particular affective responses. In previous work, the same terms have been used to denote different thermal ranges. "Warm", for example, has been used to refer to 38°C [28], 34°C [56], or a range between 2-10°C [94]. Further, results suggest that associations between particular temperature ranges and affective responses are neither stable nor consistent across different contexts and tasks: In one study different participants preferred either "cool" (-11°C to -8°C) or "warm" (2-10°C) sensations to support affective regulation, with the cold temperature range described as "relaxing" and "calming" [94]. In a different study, similar pleasant and low-arousal vocabulary was used to describe far warmer (35-38°C) stimuli [44]. By contrast, another study [7] found that participants associated similar temperature ranges — 0-10°C and 30-40°C — with *negative* valence and *high-arousal*, respectively. It seems likely that associations between thermal and affective qualities are not so simple or direct as anticipated, and not tied to precise temperature ranges. Rather — as found in some work outside HCI — they seem likely to vary significantly with context, history, and with accompanying sensory factors [e.g. 18, 62, 96].

Another obstacle to designing and discussing thermal interaction is that people often find it difficult to describe thermal and other sensory experience in a nuanced manner [73, p. 206]. Previous work in HCI, architecture [24] and thermal standards [5, 67], typically resorted to simple, broad thermal terms (e.g. "warm") with qualifying adjectives such as "neutral", "very" and/or "slightly". However, as our analysis will show, this vocabulary captures only a thin slice of the richness of situated thermal experience. Further this vocabulary is known to translate poorly between different languages and cultures [4, 47]. For instance, translation of English thermal terms into Korean and Japanese reveals mismatches in nuanced thermal connotations. The most direct translation for "warmth" in both Korean and Japanese already carries positive connotations which are not present in the English term — something which creates confusion when measuring thermal comfort, for example [4, 47]. These issues

(To the tune) Butterfly Loves Flowers

Warm rain then sun and breeze break the frozenness.
Willow eyes and plum-blossom cheeks,
I already feel the vitalisation of the spring heart.
In this mood of wine and poetry, who is here with me?
Tears melt the fading makeup, the huā diàn is heavy.

I bring out the spring jacket embroidered with gold thread.
Reclining against the mountain-shaped pillow,
this pillow has slowly worn down the phoenix hairpin.
Alone I hold this dense sadness, no pleasant dreams,
By the end of the night I am still trimming and tending the lamp's wick.

蝶恋花

暖雨晴风初破冻
柳眼梅腮 已觉春心动
酒意诗情谁与共
泪融残粉花钿重

乍试夹衫金缕缝
山枕斜欹 枕损钗头凤
独抱浓愁无好梦
夜阑犹剪灯花弄

Figure 2: A Cí poem by Lǐ Qīng Zhào [10] translated by the first author. [1]

point to the need for a more inclusive and sophisticated conceptual framework for discussing thermal experience.

Finally, as recent work has argued, HCI research should address perceptions and perspectives outside of its general Western bias [3, 48]. Work which has been foundational in haptics research [77, 78], for example, is grounded in empirical work on monocultural, Caucasian-American samples [36, p. 532]. Not only does this limit the field's ability to address the diversity of real-world experience [12, 40, 52], but it marks a missed opportunity to enrich our (design) languages and cultures with new ideas, concepts and ways of seeing [see e.g., 11, 54].

2.2 Linguistic Characteristics of Interactive Experience

Linguistic analysis has long been an important tool in understanding experience and behaviour [e.g. 20, 22, 23, 54, 55, 100] and increasingly researchers have turned to the potential of cross-cultural lexical analysis [e.g. 22, 54, 55, 100]. Recent work has analysed non-English languages to extend understandings of crossmodal multisensory experience [80], and analysed untranslatable terms in other languages, to improve cross-cultural communication and enrich English-language understandings of well-being [54, 55]. In the latter work for example, Lomas' analysis reveals the breadth of associations world languages bring to the concept of "happiness": from satiation in the Georgian *shemomedjamo* to existential warmth and intimacy in the Danish *hygge*, and different senses of elevated bliss in the Urdu *anand* and *sarshaarii*.

Recent work in HCI has taken a similar path. For example, research in haptic interaction [66] explored the constructive power of English language vocabulary in describing and communicating haptic experiences, connecting experiences with vibrotactile stimulation to an experiential vocabulary. This work provided a vocabulary to articulate the rich and complex range of sensory experiences with vibrotactile technologies, enabling communication between designers, users, and engineers. Other HCI studies have taken a more cross-cultural perspective. Matjeka et al. [60], for instance, articulated meanings from the Danish lexicon around games and play, to broaden the perspective on bodily play. Meanwhile, Mueller et al. [65] turned to specific German and Chinese words — "Erfahrung" and "Erlebnis", as well as 经验 "jing yan" and 体验 "ti yan" — to articulate aspects of bodily play experience, which unfold on different time scales and have distinct experiential qualities. Crucially, these examples do not limit themselves to articulating the experience of users of non-English languages, but show how attention to meaning in other languages helps *clarify* experiences which may be shared by native English speakers, yet are difficult to see and articulate in English. The present work aims to do this in the context of thermal interaction.

2.3 Cí Poetry

In sensory and affective psychology, researchers have often turned to particular art forms and artists to shed light on experience or provide exemplars for study [2, 23, 82]. In particular, researchers

[1] "Huā diàn" is a decoration worn on the brow. A published translation of this poem by Egan [25, p. 118]: "Warm sunlight and pleasing winds, the ice begins to melt. Willow eyelids and plum-tree cheeks, the excitement of spring stirs in my heart. A taste for wine and poetry — who will share it with me? Tears dry on fading powder, the inlaid hair-clasp heavy. I try on a lined jacked with gold-thread embroidery. Resting my head on the mound-pillow, my phoenix hairpin is dislodged. Alone I clutch dense sadness, no pleasant dream comes. Late at night I trim the lamp wick, toying with it." See our discussion of issues with this translation in Section 7.4

have drawn on individual poets as a rich store of sensory metaphor and description. Poetry by Shakespeare has informed psychology on scent-sound correspondences [23], and poetry by Rimbaud [58], Poe, Shelley, and Kipling [59] have served as a source of metaphor and imagery related to other sensory correspondences.

Among world literary forms, classical Chinese poetry is particularly noted for its compact expressivity and description of experience [91]. This is exemplified by its influence on the 20th century *Imagist* movement, which is credited as bringing similar qualities to 20th Century English poetry [74, pp. 127-137]. Of particular note is Cí poetry. Originally written as song lyrics, Cí authors often drew from folk traditions, while placing strong emphasis on first-person experience and the natural world [8, 42, 104]. In line with this, Cí is considered a particularly rich source of emotional and experiential description [9] (see Figure 2 for an example). In contrast to more official and political literary forms, Cí was often written to share experience with friends and family [33, p. 391]. As such the form often focuses on intimate personal expression and reflection [33, p. 391], and an immersive description of personal experience from within [104, p.1]. This leads to a particular emphasis on the faithful rendering of experience [101, p. 534], emotional nuance, and rich sensory imagery [42], which scholars have suggested retains relevance in illuminating contemporary experience [42, 101]. These qualities led us to Cí as a source for our analysis.

Many of the most acclaimed poets of the Tang and Song eras wrote in Cí form. Two such poets stand out in particular for the purposes of the present work: First, 苏轼 Sū Shì is considered one of the central writers of the Chinese literary tradition [33, p. 390]. His Cí texts have been noted for their expressive use of natural imagery to express emotional experience [26]. Second the poems of 李清照 Lǐ Qīng Zhào [2] have been championed by ecofeminist researchers for their expressive descriptions of bodily experience in the environment [42]. It has been argued that her work emphasises the entanglement of embodied experience with environmental agencies [42]. In this respect, her work has been connected to modern Western *entanglement* theories such as Barad's *agential realism* [42], which HCI researchers have drawn upon to address the complex relations between humans, machines and environments [30]. An exhaustive account of the history of Cí is beyond the scope of this paper, but we refer interested readers to [9, 32, 70] for more detail.

3 METHOD

A vast amount of Cí poetry has survived into the present day, and even individual anthologies contain around twenty thousand Cí poems [37]. Rather than attempting to analyse this entire body of work, we followed the approach taken by previous work in sensory psychology, focusing on particular authors [e.g. 23, 58, 59]. This approach is in line with guidance on qualitative analysis and experiential research which suggests that more compact and focused corpuses support coherence and concreteness in results [13, 95]. We selected two representative authors — 苏轼 Sū Shì and 李清照 Lǐ Qīng Zhào, for reasons discussed in the previous section.

[2]Also transliterated as Li Qingzhao

We conducted a qualitative lexical analysis using grounded theory (GT) [89]. Grounded theory is a theory-generating approach, suiting our goals of developing a framework for thermal interaction design, and has been used in similar work in both HCI and psychology [e.g. 21, 55]. Rather than developing a general theoretical account of thermal-affective associations, we aimed to construct a framework to serve design specifically: to connect descriptions of thermal and thermal-affective experiences in rich contexts to issues in thermal and affective design.

Analysis was conducted on the original Chinese texts by the first author, a Chinese native speaker. We opted to focus on the original Chinese texts for two reasons: (1) While many English translations of Cí poems have been published [e.g., 26], not all poems relevant to our study have been translated into English. (2) In a number of cases, available translations proved inadequate for our purposes: Details in the original poems, relevant to thermal affective experience were lost through linguistic choices which seemed intended to serve fluency, English rhyme or concision (see Figure 2 and footnote 1 for an example).

We followed the Strauss and Corbin approach to GT in [89]. Our analysis involved two stages. First, corpus construction with a pre-selection of relevant Cí poems; second, inductive coding and theoretical sampling (Figure 3). While interview-based GT, in particular, emphasises the practice of collecting data alongside analysis, informed by that analysis, Strauss and Corbin are clear that GT can also be applied using already-collected data [89, p. 331]. In this case, they emphasise the need to be aware of gaps and limitations in the data (which we address in Section 7.3). This is the approach we took in this study (see also e.g. [54, 55]). In the first stage, we collected all recorded Cí poetry from "The Collection of Cí Poetry in Song Dynasty" [37], which included 352 Cí poems from Sū Shì and 22 from Lǐ Qīng Zhào. We collected seven additional Cí poems by Lǐ Qīng Zhào from "The Collection of Lǐ Qīng Zhào's Poems and Cí poetry" [10]. In total, the collection includes 381 Cí poems. We then searched this corpus for relevant descriptions of thermal perception. We reviewed the corpus for *explicit* accounts of thermal experience: searching for individual characters which described felt thermal experience, such as "Liang" 凉 (cool/cold), "Leng" 冷 (chilly), "Han" 寒 (cold), "Dong" 冻 (frozen), and so on. We also reviewed the corpus for passages that featured *implicit* description of thermal experience without using characters for thermal experience. For example: "Flaming clouds condense, I wipe away the beads of sweat.". Poems without either explicit or implicit description of thermal experience were excluded. This search resulted in a corpus of 154 Cí poems. All of these were analysed and contributed to our final results. To support deeper understanding and inspire future research we identified 70 excerpts, which provided particularly strong demonstrations of issues and concepts in our framework. These are provided in auxiliary materials translated in full into English.

The second stage involved *inductive coding* following the three coding steps described by Strauss [89]: open coding, axial coding and selective coding. During *open coding*, we labelled concepts in the 154 Cí poems. For example, we grouped affective descriptions (words, phrases) such as 寂寞, meaning "lonesome" under the label "explicit affect". In the *axial coding* step, we examined these concepts and clustered them into themes. For example, the concepts

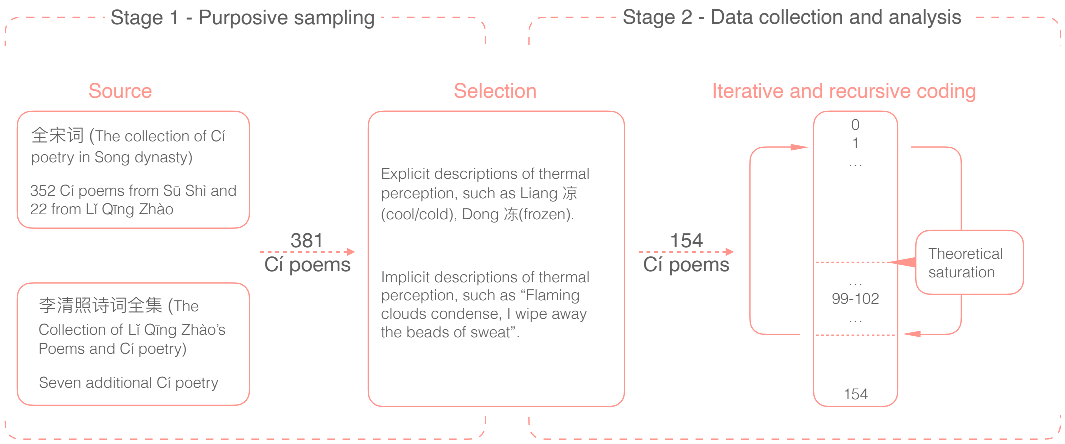

Figure 3: Corpus construction and data analysis

'thermal (sensory) modalities' and 'cross-sensory associations' were aggregated into the category 'multisensory perception'. In the *selective coding* step, we identified core categories that were grouped within themes. We attempted to elucidate how these categories are related, providing insights into thermal-affect association and experience. Each poem was analysed as a stand-alone experiential episode. We coded every episode, following guidance to return to previous episodes in light of later coding [89, p. 331]. Theoretical saturation was reached at around two-thirds of the corpus, but we continued analysing to identify high quality expressive excerpts for the design framework. Our analysis was informed by our knowledge of issues in the design of thermal-affect experience in previous HCI research, but not restricted to these issues. In particular, while the imagery and situations described are often culturally specific, we approached this analysis reflexively, translating it through our experiences in modern European and Asian settings to draw out concepts and principles that speak to a wider range of contexts. This helped our analysis to serve as a basis for our design framework (outlined in Section 5).

4 RESULTS

In our corpus, we identified three high-level themes: (1) Patterns of vocabulary for describing thermal perception and experience; (2) multisensory aspects of thermal experience; and (3) relationships between thermal and affective experience. In the following, we outline each theme, illustrating with excerpts from the poems. The imagery in these excerpts is often expressive and evocative, and they may directly inspire ideas for design. While we see this as a valuable outcome, this is not our primary goal. Rather, excerpts are chosen to articulate and illustrate wider qualities, principles, and concepts that apply more broadly, and can inform reflection and design in a wide range of contexts. Original Chinese texts for all excerpts can be found in the auxiliary materials, referenced via ID numbers.

4.1 Theme: Vocabulary for Thermal Experience

The texts in our corpus used rich language to convey thermal experience – both explicitly via specific thermal experience terms, and more implicitly. In the explicit descriptions we identified eight distinct terms: 寒 "han", 冷 "leng", and 凉 "liang" convey cold and chilliness. 霜 "shuang" conveys frost and frostiness, 冻 "dong" conveys frozenness and solidity. 温 "wen" and 暖 "nuan" both convey warmth. Finally, 和 "hé" conveys a satisfying thermal state, not attached to a specific temperature range.

Beyond simply conveying temperature, these terms carry associations with nuanced aspects of thermal experience not always apparent in English language terms. For example, the characters 温 "wen" and 暖 "nuan" both convey experience of warmth, but with different material qualities. "Wen" conveys an *enveloping, flowing* warmth: for example, "With spring rain the last of iciness fades, warm (wen) wind comes to cold ashes" (ID66). Meanwhile, "nuan" conveys *radiant* warmth — "The sun's warmth (nuan) on the mulberry creates a cascade of light" (ID63)

Language patterns around these characters served to further qualify and extend the range of sensory associations and sensory-affective connotations conveyed. We refer to these as "patterns of vocabulary". We identified seven such patterns which were important in conveying thermal-affective experience (see Table 1 for an overview).

The first pattern conveys the *valence* of the thermal experience: its pleasantness or unpleasantness. First, some characters imply a valence on their own. For example, 冷 "leng" implies unpleasant coldness, whereas 凉 "liang" sometimes carries a positive connotation : "Having won the tea-making competition, the victory is worth a thousand cups. *Liang* (coolness) emerging [...]" (ID4). A particularly interesting example is the character 和 "*hé*". This "untranslatable" [55] word indicates a sense of physical, emotional and mental satisfaction, but does not attach to any specific temperature range. We found this character could be used to convey pleasant warmth in visual contexts, e.g. "on the south corner of the ornate pavilions, the setting sunlight sheds *hé* (satisfying warmth)" (ID18).

It was also used to convey satisfaction with other thermal states, e.g. 和风弄袖 “the *hé* (satisfying) breeze teases our sleeves” (ID70)[3].

The second pattern, *experiential intensity*, describes qualitative differences in the felt *intensity* of thermal experience. For instance, 嫩寒 “nen han” (ID33) for tender and soft coldness, or 微寒 “wei han” (ID49) for a faint coldness.

The third pattern conveys *temporal and seasonal* qualities. Here, modifying terms are appended to the character, somewhat akin to the use of adjectives in English. For example, some excerpts conveyed seasonally specific kinds of coldness, e.g.: 春寒 “chun han” (ID30)—the spring coldness; 初寒 “chu han” (ID38)—the newly arrived coldness (implying a seasonal change from autumn to winter); 旧寒 “jiu han” (ID9)—the old coldness (implying a seasonal change from winter to spring).

The fourth pattern conveys *multisensory* qualities of thermal experience. Again, this is achieved by appending modifying terms. For example, 苦寒 “ku han” (bitter coldness, ID5) invokes the sense of taste [4]. 轻寒 “qing han” (ID8) describes the light (rather than heavy) coldness, invoking mass perception.

The fifth pattern conveys the *material* quality of the experienced thermal cues. This includes the use of “wen” (liquid, or immersive warmth) and “nuan” (radiant warmth), discussed above, but also other excerpts which described thermal qualities via physical materials. Examples included snowflakes melting on the cheek (ID67), and the touch of cold fabric: “The night's chill settles on my pillow and bamboo mat” (ID2). While not all examples involved explicit physical touch, all invoked tactile experience.

The sixth pattern concerns *thermal agency* - the perceived activity or passivity of a thermal phenomenon. For instance, while 凉 “liang” and 冷 “leng” describe different intensities of coldness, “leng” also signifies a more active, even aggressive, cold. For example, “the cold (leng) penetrates garment and sleeves” (ID14), or “coldness (leng) soaks the autumn emerald sky” (ID15).

The seventh pattern foregrounds *thermal imagery*: This describes cases where visual language with thermal associations is used to enrich the expression of experience, even if the thermal experience itself is not necessarily in focus. For example, in the excerpt 明月如霜 (ID68) “frost-like moonlight”, the character for frost, 霜 “shuang”, is appended to the characters for moonlight, invoking a thermal quality without implying that coldness is felt. Elsewhere, in a similar way, distant clouds are described as “frozen solid” (ID34).

4.1.1 *Thermal Metaphors.*

In our corpus, we also identified thermal language that did not necessarily denote experienced thermal states but functioned figuratively: conveying emotional, aesthetic, and other aspects of experience. Some thermal metaphors were used to describe emotions. For instance, the character 凉 “liang”, indicating “cold”, was used to convey different kinds of sadness: 凄凉 *“qi liang”, (ID65)* captures one's own “dismalness”, while 悲凉 *“bei liang”, (ID69)* captures a stronger sadness, either in oneself or visible in another. Similarly, 冷落 *“leng luo”* (lit. “cold fall”, “drop”, or “descent”) — combines thermal metaphors and vestibular perception to express desolation and isolation (e.g. ID6).

Visual thermal cues can also serve as metaphors for the passing of time, often carrying affective connotations. For instance, frost (霜, “shuang”) is associated with autumn coldness, and features in metaphors for age, such as 霜鬓 (*“shuang bin”*), meaning “white temple hair”. Similarly, apricot blossom is associated with spring warmth and serves as a metaphor for adolescence and young adulthood (e.g. ID55).

Finally, thermal metaphors can be used to describe affective and aesthetic experience — for example in music appreciation. In one excerpt, music is described as “snow flakes flowing in the midst of a fire-ocean, bringing coolness (to the universe)” (ID56). Another describes “spring water flowing into the strings [of an instrument], and frost falling on the notes” (ID57). As this illustrates, thermal metaphor is often multisensory — highlighting synergies or associations between experience across different senses.

4.2 Theme: Multisensory Thermal Experience

Thermal experience is often associated with haptic perception — feeling the sun's warmth on our skin, or touching cold objects. However, in our corpus, a variety of other sensory modalities contribute to, and in some cases even dominate, the thermal experiences described — visual, auditory, olfactory, internal bodily perception, and even emotional modalities. In many extracts thermal experience is conveyed *entirely without reference to the haptic modality*. In one extract (ID1), for example, the feeling of summer heat is perceived through sound (the chirping of cicadas, dampened by tall and thick trees), scent (the diffusion of incense in hot air), and vision (a view of pomegranate blossom distorted by heat-haze). In such cases thermal cues are often *indexical*: phenomena which do not simply *symbolise* thermal properties but have a direct causal relationship with them [6]. Visual heat haze is produced by temperature gradients, cicadas and blossoms arrive with hot weather, and scents diffuse more strongly in warm air.

In the corpus, we find that multisensory perception contributes to thermal experience in three ways. First, thermal-haptic perception can be **augmented** by thermal cues from other senses, e.g. “The night's chill settles on my pillow and bamboo mat, amplified by the sound of the autumn crickets” (ID2). It can also be enhanced by **contrast** with the other senses, as when the sight of hot energetic dancing contrasts with imagery of intense cold. “The Yu Yang drumming continues, jade hair pins have fallen in the dance, sweat dampens and softens the silk. [...] Ice forms on the ink before the poem is done” (ID3). Finally, different haptic modalities can **come together** in synergies. For example, an internal bodily coolness from drinking tea synergises with the external coolness of breeze on skin: “Having won the tea-making competition, the victory is worth a thousand cups. Coolness emerging, I feel the limpid breeze beneath my arms” (ID4).

A subset of multisensory thermal experiences in our corpus involve *crossmodal* associations: a perceptual phenomenon whereby one sensory modality influences the perception and interpretation of stimuli in another [86]. Examples include the influence of auditory pitch on visual size [72], and the influence of colour on tactile perception of shapes [29, 50]. In contrast to the multisensory examples above, crossmodal correspondences are not necessarily indexical (e.g., the observed phenomenon needn't have a direct

[3] In our corpus all uses of *hé* are related to thermal expression. In other contexts it can also refer to harmony and peace.

[4] 苦 retaining the strong association with taste which has been somewhat lost in the English “bitter”

Table 1: Patterns of vocabulary for describing thermal experience

Pattern of vocabulary	Function	Examples
Valence	Describes satisfying states (either within the body or in the environment) and thermal valence	"setting sunlight sheds *hé* (warmth)" (ID18), 和 "hé" in positive valence; "the *leng* penetrates garment and sleeves" (ID14), 冷 "leng" in negative valence.
Experiential intensity	Specifies the intensity of perceived thermal cues	嫩寒 "neng han"—the tender and soft coldness (ID33). 微寒 "wei han"—the faint coldness (ID49), etc.
Temporal quality	Specifies the temporal qualities of thermal cues	Temporal feature:夜凉 "ye liang"—the night coldness (ID2). 春寒 "chun han"—the spring chill; 初寒 "chu han"—the newly arrived coldness (implies a seasonal change from autumn to winter)
Multisensory feature	Indicate sensory features of the thermal experience	苦寒 "ku han" —the bitter coldness (ID5); 轻寒"qing han"—the light (rather than heavy) coldness.
Material quality	Specifies the material qualities of thermal cues	Material quality: 温 "wen"— liquid, flowing warmth, 暖 "nuan"— radiant warmth.
Thermal agency	Specifies how thermal cues are perceived as acting on the perceiver	Being dominant and aggressive: coldness soaks the autumn emerald sky (ID15), the coldness penetrates the garment and sleeves (ID14). Being active: the warmth cracks the frozen world (ID17). Being tangible: The night-shining withdrew and limpid coldness spills out (ID60), etc.
Thermal imagery	it serves as a descriptive thermal quality for rhetoric use	霜入拨 "shuang ru bo"—plucks (on an instrument) frosted (ID57). 云凝冻 "yun ning dong"—clouds solidified and in freeze (ID34), etc.

causal relationship to thermal experience). In one example, the coldness is associated with bitter tastes "North of the Great Wall spring arrives, bitter cold" (ID5).[5] In other excerpts coldness "falls" (ID6) connecting thermal and proprioceptive experience, and associations are found between thermal and mass perception (ID8) or visual perception (ID7). [6].

In sensory terms, all of the examples above concern *exteroception* — the perception of external states. We also found examples related to *interoception* — thermal experience of internal bodily states. Such *internal* thermal experiences could follow from bodily exertion such as dancing (ID3, 22), or from the consumption of food and drink (ID4, 24). These internal and external perceptions interacted in different ways — in harmony, contrast, or by merging together. For example, warmth from drinking wine harmonised with the external warmth of spring: "Thick Hu Po and fragrant Lü Yi [7]. It reaches my sorrowful gut and stirs the sense of mid-spring" (ID24). Elsewhere, internal warmth contrasted with, and even nullified the external cold: "Drinking heavily and making poems, in their drunkenness no one notices the absent felt mats" (ID25) (mats provide insulation against the cold stone chair). Finally, internal and external cues could even merge together and become indistinguishable. One excerpt expressed this via a dramatic circularity between body and environment: "Flaming clouds condense, I wipe away the beads of sweat. The sweat condenses into flaming clouds" (ID7).

[5]In English, the association between "bitter cold" and taste has faded, but in Chinese the association remains clear.
[6]Note, we do not take this as evidence of crossmodal *correspondences* — a scientific construct (see [81, 84]). Rather, they highlight cross-sensory *associations*, which provide a source of design ideas and hypotheses for future study.
[7]Hu Po is an amber-coloured grain wine, Lü Yi (lit. "green ants") is a type of fragrant, unfiltered, rice wine.

4.3 Theme: Thermal Affect Relationships

In our corpus, thermal experience often carried affective connotations. However, we did not find *consistent* associations between particular thermal and affective states. Warmth, for example, could be associated with vitality (ID17), sleepiness (ID21), sadness (ID28), or happiness (ID29). Similarly, coldness could be associated with lonesomeness (ID30), joy (ID4), sadness (ID31), or melancholy humour: "The strength of wine gradually disappears, and the wind is soft, sou-sou [a mimetic word for chill and fast wind], my broken hat is so melancholy that it is reluctant to leave my head." (ID32).

Beyond one-to-one associations, we found cases where one thermal perception related to complexes of multiple affects. This might mean a cluster of similar affects, as when a chilly autumn night is associated with worry, loneliness, melancholy and dismalness (ID35). It might also mean more contrasting affective states e.g. warm spring wind associated with gentle happiness mixed with a lonely sense of melancholy and fleetingness (ID64). Likewise, multiple aspects of thermal experience can be associated with one (or more) affect: for example, sadness was associated with the sound of rain on paulownia leaves, cricket chirping at night, and the touch of a cold pillow and bamboo mat (ID2).

4.3.1 Thermal-affect modulation. Beyond direct associations between thermal and affective qualities, affective and thermal experience influence each other in various other ways. We refer to this as *thermal-affect modulation.*

Direction 1—Thermal perception modulates affective state (Figure 4). We identified four ways in which thermal perception modulates affective state. First, thermal perception **induces** affective

Figure 4: Thermal experience modulates affect

response: e.g., sudden warmth induces positive affect and raises arousal: "Warm rain then sun and breeze break the frozenness. [...] I already feel the vitalisation of the spring heart" (ID17). Second, thermal perception provokes **reflection** on affective state: e.g., morning coldness provokes reflection on life's difficulties: "...Gradually the white glow of the moon withdraws, the morning frost bright in my eyes [...] this burdened life has its limits, forever wearing myself out with such labour brings little joy" (ID36). Third, thermal experience **motivates** a certain mindset. For example a cherishing and future-facing outlook: " Thin wind rustles the willows [...] from the viewing platform blossom and spring water abound. Mist and rain come to darken the city's countless homes [...] Let's not yearn for the old hometown: build a new fire to taste the new spring tea, enjoy poetry and drink while this springtime spirit is here" (ID37). Finally, thermal experience can **augment** existing affective experience, for instance intensifying sadness at departure: " [...] Fierce winds blast the Li Ting[8], ice crystalizing tears. The snow means to keep you, but you cannot stay. With your departure joy is gone" (ID38).

Figure 5: Affective state modulates thermal experience.

Direction 2—Affective state modulates thermal experience (Figure 5). We also found examples where affective states **induce** thermal experience: as when music prompts aesthetic chills and warmth: "the wind and rain beneath your [musician's] fingers create ice and fire in my gut, putting me in turmoil" (ID39). Affective states also draw attention to external thermal cues: **intensifying** (ID40) or **nullifying** thermal perception (ID25 excerpted above), or **reversing** the perception of thermal cues and associations, as when sadness makes the author perceive coldness in fire (ID41).

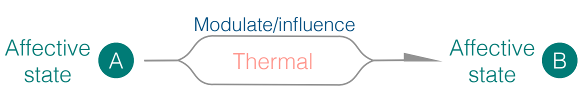

Figure 6: Thermal perception modulates unfolding change in affective experience .

Influences on the Unfolding of Experiential Change. While many excerpts described momentary experiences, or outcomes, others described the unfolding of experiential *change*. For example, change in affective experience, influenced by thermal perception (Figure 6), as when an episode of rain marks a shift from elation to dejection (ID65): "[. . .] High on the city tower I feel elation. Rain clouds pass briefly. [...] The mundane world is sad and dismal, and with the turn of my head, my life has passed me by". Other excerpts described the reverse case: unfolding changes in thermal experience modulated by affective state (Figure 7). In one excerpt, as the author reflects sadly on their inability to help cold and starving people, this initiates a change from mere visual perception of cold in the landscape, to an intense bodily sense of cold, in rigid fingers and frozen beard (ID45).

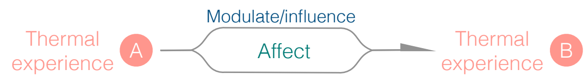

Figure 7: Affect modulates unfolding change in thermal experience .

4.3.2 Time scales of thermal-affective experience. Experiences in our corpus played out over a wide range of time scales. Some were momentary and immediate, but others unfolded over minutes, hours, or longer. These different time scales were associated with different *qualities* of thermal-affective experience. In particular, thermal experience was more at the foreground of experience in shorter experiential episodes (i.e., from moments to minutes), compared to more extended episodes, with more explicit thermal language in shorter episodes. For example: "Cold crows cover the sparse fences, competing to enjoy the cold tree and its jade blossoms" (ID52 our emphasis). Active qualities were also more prominent at shorter time scales (e.g. penetrating cold (ID14), and warmth "cracking" the frozen world (ID17) — see Section 4.1), often associated with strong contrasts and intensities. By contrast, at longer time scales (i.e., hours or longer) thermal experience remained more implicit — articulated via seasonal imagery and experiences of fading scents, for example.

Thermal-affective experience on different timescales could interact. For example, an affective state might be associated with both long, seasonal, change and the experience of the moment — e.g. loneliness is associated with both the slow passing of the summer and the immediate, cold, touch of a bamboo mat (ID 50).

5 A DESIGN FRAMEWORK FOR THERMAL AND THERMAL-AFFECTIVE EXPERIENCE DESIGN

On the basis of our analysis, we propose a framework to support the design of thermal interaction and thermal-affective experience. We call this a *design* framework specifically, as it translates our findings to serve the needs of thermal design in a wide range of contexts. It provides vocabulary, conceptual guidance, and perspectives to prepare design actions.

This framework is structured around three design concepts which can support design researchers and practitioners in generating new ideas, analysing existing designs, and clarifying design concepts and knowledge contributions [88, 106]. Figure 8 shows a summary of the design framework.

[8] 离亭the last shelter outside the city walls, where the closest of friends and relatives bid farewell to the departing.

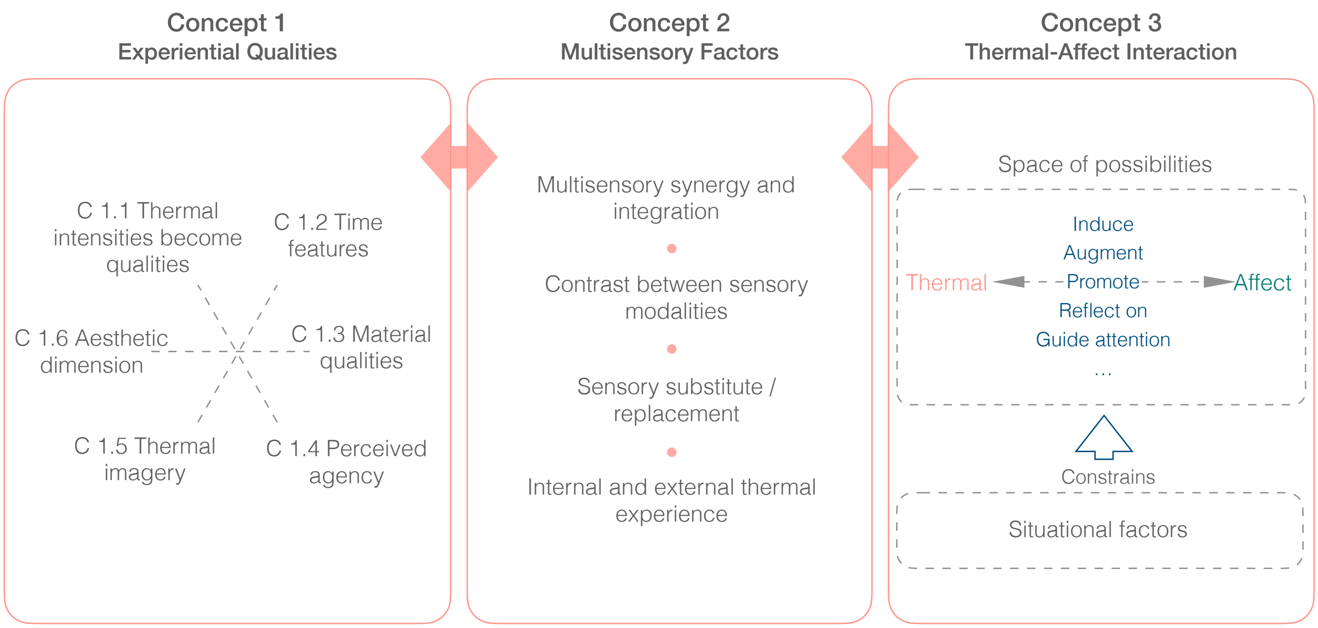

Figure 8: The design framework for thermal interaction and thermal-affective experience.

5.1 Concept 1: Clarifying and Addressing Experiential Qualities

First we identify ways that designers can clarify relevant experiential qualities, and support these through design. In this section we draw on the rich vocabulary of thermal perception identified in Section 4.1 to help designers articulate and explore qualities of thermal experience. We unpack those findings (summarised in Table 1) into seven principles and prompts relevant to the quality of thermal experience.

C1.1: In thermal experience, intensities become qualities. When we implement thermal cues in technologies we need to think in terms of quantifiable control parameters. Because of this, it is easy for the design of thermal *experience* to be framed in terms of quantifiable intensities that map directly to these control parameters: simple quantified thermal terms like "very cold" and "slightly hot". However, our lexical analysis illustrates how, in situated experience, such thermal intensities take on a far greater *qualitative* complexity which designers should address. We found that a coldness, for example, could be faint (嫩寒 "neng han" ID33), soft (微寒 "wei han"ID49), unpleasant (冷 "leng"), or carry positive connotations (凉 "liang"). Warmth, equally, could be enveloping (温 "wen") , or radiant (暖 "nuan"), or much else besides.

In short, the qualitative experience of thermal intensities quickly goes beyond the language of simple intensity and measured magnitudes. To illustrate, imagine an icy winter's day: When we first step outside, we feel a sharp, shocking, intense cold. After some time, our experience changes: while the temperature (the intensity of the cold) has not changed, the feeling of coldness is no longer so sharp and intense. Later, we touch the fresh, soft snow, making direct contact with a cold material which transmits cold more efficiently than air. Nonetheless, it now feels qualitatively different than the sharp, intense cold that hit us when we left the house: our exploratory attitude, the snow's tactile softness, and our aesthetic enjoyment all influence the quality of the experience.

These experiential intensities map less directly to engineering variables, yet attention to them, and the conditions that support them will be important for designers seeking to create involving and affective experiences. We articulate particular aspects of this qualitative experience below.

C1.2: Consider temporal features of thermal experience. Designers should consider how the thermal experience evolves over time: both during the episode and over longer-term use. New thermal cues will be experienced differently than those that are familiar, or that users have acclimatised to (see Section 4.1). Moreover, successions of thermal cues can accumulate over time, allowing designers to work with contrast and synergy, to create more complex overall thermal experiences. For example, a cold blast of air, dampness, and a slowly growing ambient chill may evoke the sense of autumnal cold and it's characteristic mood (ID13). This calls designers to look beyond static and isolated thermal experiences and to consider the effect of their designs at different time scales, taking into account the role of memory and anticipation. Importantly, attention to dynamics of the thermal experience can provide a bridge to technical implementation: specifying durations, ramp-ups and ramp-downs in place of static magnitudes [29].

C1.3: Thermal cues have material qualities. The materials that mediate our thermal experiences significantly influence those experiences. The radiant heat of the sun and a warm bath, for example, feel quite different. They differ in terms of directionality, thermal conductivity and the feeling of haptic contact. Similarly, it is a different experience to touch soft snow, a wool scarf, or a metal bar, even if they all have the same temperature. As such, designers of thermal interactions should consider how material qualities can be leveraged as design parameters. To create a sense of thermal fluidity on the body, for example, designers might manipulate **directionality** — the perception of where thermal cues originate and project — to create a sense of movement. In wearables, designers might also control **thermal conductivity** via more or less thermally conductive materials to manage the dynamics of thermal change; or they might consider how the **texture** of the materials either enhance or reduce the sense of fluidity. As shape change technologies develop, designers might vary texture to change the textural quality of thermal cues over time: mimicking melting or freezing, for example.

C1.4: Thermal cues can take on a perceived agency. Many excerpts in our corpus assigned agency to thermal stimuli: for example, companionable (ID18,21), aggressive (ID14), or dominating (ID15). We suggest that attention to this activity or passivity can be important in helping designers deliver thermal experiences which are engaging, context-appropriate, and well-accepted by users.

Our analysis, points to several design parameters that may help in thinking about the activity or passivity of thermal cues. First, **contrast**: Larger, more noticeable thermal contrasts and sharp onsets or changes can appear more active (see Section 4.3.2). Second, **proximity**: thermal cues delivered via wearables or devices close to the body may be perceived as more active, in part because this supports sharper contrasts, faster changes, and greater localisation. By contrast, ambient thermal cues (whether haptic or delivered via other sensory modalities), may often have a more passive quality — though examples in our corpus show how very strong ambient thermal queues, such as strong pervasive cold, can still feel dominating. Third, a related factor is the presence of the cue in the **attentional foreground or background**. Thermal cues may need to be in the foreground of awareness to be perceived as active, and to achieve related novel effects which enrich experience. Cues perceived as active may be effective to convey alerts, and other information. Meanwhile subtler thermal cues, which remain in the background of awareness, are likely to feel more passive, offer users more agency in guiding their attention, and may be better tolerated in regular use. Between these two poles, there is a large space of design which can be used in emotional regulation applications, and to invoke diverse affective responses.

C1.5 Thermal imagery - thermal experience is often a supporting factor. Related to considerations of whether thermal cues occupy the foreground or background of awareness: thermal cues will not always be the central focus of a design. They may often play a background role, contributing to an overall atmosphere via multisensory synergies or subtly conveying information. This connects to what we called *thermal imagery* in our analysis — imagery which enriches expressivity via thermal associations. Examples of this in English include terms like "cold rage" to express emotion and the use of crossmodal associations (e.g. "warm light") in the description of other phenomena. Similar associations might be leveraged in thermal experience design. As showcased in our result, moonlight can be described as "frost-like" or "wintry" (ID68). Designers of VR and immersive lighting systems might employ subtle thermal cues to create a richer, and implicit multisensory experience than with light alone. More broadly, thermal imagery can facilitate communication of tacit, affective and aesthetic experiences in cases where the thermal cue remains implicit, or in the background of awareness.

5.1.1 C1.6 Aesthetic dimensions of thermal-affective experience. In our corpus, metaphorical use of thermal language was often used to capture intangible aesthetic and affective experiences, such as the affective and physiological response to music (e.g. ID46, Section 4.1.1). This points to the potential for thermal design to support aesthetic experiences. One extract describes the "frosted" strings of a plucked instrument (ID57) — associating iciness with percussive, sudden events — and combining this with imagery of warm, flowing spring water, suggesting a contrast between short cold and slower warm stimuli. Another extract addresses the dynamics of musical experience in terms of cooling, describing snowflakes falling on a fire ocean before closing on a sense of coolness (ID56). Previous work in HCI has sought to simulate the aesthetic feeling of chills running down the spine [39, 43]: images in our corpus suggest a far broader design space for the thermal augmentation of aesthetic experience, with cues varied over time in a more complex manner, akin to music (see C1.2 above).

5.2 Concept 2: Leveraging Multisensory Experience in the Design of Thermal Cues

When considering the design of thermal cues, we might most immediately think of thermal-haptic modalities. However, as we have noted, thermal perception can also occur via other senses. Visual (e.g. colour schemes), auditory (bright or "warm" timbres), olfactory (menthol or spicy scents), and other sensory modalities can convey thermal experience. In some cases, haptic may play a small, or even absent, role. This observation expands the potential design space for thermal experience, but also increases its complexity. To address this complexity, and clarify possibilities for analysis and design, we identified four ways in which different senses can work together in thermal experience (Section 4.2) .

Synergy. — Designers may use consistent cues across different sensory modalities aiming at an *integrated* thermal experience: a complete and harmonious thermal perception (e.g., ID4,18). A special case of this is **augmentation**, when haptic thermal perception is intensified by cues from vision, taste, or other modalities — e.g intensifying a perception of warmth with redder colours and spicier tastes [41, 45]. Cross-sensory associations may be relevant here, with promising candidates from our lexical analysis including: **Vestibular** perception of to movement in space: e.g., coldness associated with a sense of falling. **Mass**: e.g., associating coldness and heaviness and higher temperatures with lightness. **Vision**: e.g., associating colour saturation or hue ranges with higher temperatures, and lower saturations with lower temperatures. **Taste**: e.g., associating coldness with bitterness or sourness.

Contrast. — Designers may also create contrast between sensory modalities. In certain cases, this may serve to intensify or sharpen awareness of the thermal experience; as, for example, winter scenery (visual) can place the haptic sensation of heat into sharp relief (e.g. ID3). Such contrast may be useful when thermal technologies are used regularly or for prolonged periods. While thermal sensation can desensitise over time, it can be refreshed by contrast [34, 68]. Contrast across different modalities, or within the same modality over time may calibrate and renew awareness, e.g. to return a background stimulus into the foreground of awareness.

Substitute/replacement. — Finally, designers can convey thermal information entirely without the involvement of haptic sensation. Combinations of visual, auditory, olfactory and gustatory information can provide a rich texture for diverse thermal experiences (excerpts in our results and auxiliary material may provide sources of inspiration). This may be particularly important in cases where it is cumbersome, expensive, or otherwise impractical to deploy haptic thermal devices.

Internal and external thermal experience. Finally multi-sensory thermal design can address the synergy and contrast between external and internal thermal experience. Examples of internal thermal experience in our corpus include awareness of thermal states induced by food and drink (e.g. drinking tea and alcohol, ID4,24,25) and physical activities (e.g. bathing, dancing, sport. ID26,3,23). Designers might consider whether thermal technology might be used in contexts where exercise, eating, and other sources of internal thermal experience may occur. These internal thermal experiences may be congruent with, or contrast with thermal cues from the technology and may influence the overall thermal experience. They may also consider ways of eliciting internal thermal sensations, for example by integrating physical activities into the interaction. Finally, researchers interested in bodily awareness or mindfulness might consider promoting awareness and expression about the localisation of thermal cues in the body (e.g. warmth in the gut (ID24), coolness from the chest (ID4), heat in the breath(ID26)).

5.3 Concept 3: Designing for Interactions Between Thermal and Affective Experience

5.3.1 How do thermal experience and affect influence each another? Our analysis identified various ways in which thermal experiences influence affective experiences, and vice-versa (Section 4.3.1). In this section, we discuss implications of this for design.

To refresh our findings; we identified that thermal experiences may **induce** certain affective responses, or **augment** existing affect from other sources. These are the approaches most commonly taken in previous design research. Beyond this we found cases where thermal experiences **promote** particular mindsets or outlooks in the user, such as comfort, ease, alertness, or in particular **reflection**. Such mindsets may influence further interpretation of affective information or support interpretation of emotions and experiences. Consideration of these distinctions can help designers think more clearly about thermal-affective design, moving beyond simple temperature-affect mappings.

To illustrate, there are situations where immediate up- or down-regulation of emotions is valued: for example when stress risks reducing performance in an important task. In such cases augmenting or inducing affect may be the best strategy. However, for longer-term emotional management, related to mindfulness or mood regulation, it may be more effective to explore strategies to promote reflection and other relevant mindsets. Designers can also consider the reverse case: how affective experience modulates the perception and experience of thermal cues. This has received relatively little attention in previous work. Again, we identified distinct ways in which this modulation can occur. For example, affective experience may induce perception of thermal qualities (e.g. listening to music may induce chills — ID39, 46, 56). It may also guide attention to thermal cues, as when sadness draws attention to the cold (ID40) or positive, engaged feelings reduce or nullify the impact of cold stimuli (ID3,25). Such effects could be leveraged for aesthetic design: such as simulating or augmenting the experience of aesthetic chills and warmth (see Section 5.1 C1.6). Designers might also consider the possibility that awareness of thermal cues may be sharpened or diminished by particular affective states, or states of engagement.

5.3.2 How to design for thermal-affect associations? Our lexical analysis revealed no simple, consistent associations between thermal and affective qualities. Instead, we found a rich range of highly situated, context-sensitive associations. This is consistent with the apparent instability or variability in thermal-affective mappings found when comparing results from previous studies (see Section 2.1). We suggest that two questions can guide design related to thermal-affect associations.

First: **what are the conditions under which a particular thermal-affect association occurs?** This question encourages designers to take into account the situational factors that may influence the result — factors which are often moved out of the frame in controlled studies. While in one case we may find that warmth maps to positive affect, and cold maps to negative affect, this is likely to depend on the context, the way the thermal cue is delivered, and other circumstances relevant to affective state such as the narrative framing of the interaction.

Second: **what is the space of possibilities for thermal-affective association in this particular case?** If contextual factors influence associations between thermal and affective states, then rather than assuming stable mappings, designers should ask what is the space of *potential*, and relevant associations between thermal and affective experience that may arise. Further, what factors might influence the actual associations which users experience? In a particular context or interaction a single thermal cue, or a set of (potentially multisensory) thermal cues, may have one clear affective association. Equally the association may be more complex and have several potential affective associations, influenced by other factors. Thinking in terms of a space of possible outcomes and experiences frames thermal cues as influencing and nudging but not determining outcomes, with some outcomes more likely than others, but none certain. It encourages designers to pay attention to the contextual factors which will collaborate to mould these possibility spaces: Events around the interaction, culturally specific associations, the thermal context prior to the interaction, etc. Future work can clarify this approach by investigating thermal-affect associations in context, and documenting the influence of situational factors.

6 HOW TO APPLY THE DESIGN FRAMEWORK

We demonstrate the use of our framework via three case studies; analysing presentative works which deal with interactive thermal technology. We show how patterns of vocabulary and design concepts in our framework bring clarity to analysis, expand design spaces, and support ideation. The studies cover a range of thermal technologies and inquiry methods. They show how our framework expands design spaces and inspires alternative design solutions.

6.1 Case 1 - Guiding Bodily Awareness

Our first case study shows the application of our framework to design exploration, in work on heat as a design material for body-awareness [44]. Jonsson et al. developed a heating mat for the Feldenkrais exercise — a technique to support bodily awareness. They investigated several sources of thermal stimulation: instant heat pads, cold water in tubes, lights, and heating pads. Through design iterations, they developed a system which used instant heat pads embedded in a body-sized floor mat, to deliver heat to individual body parts. During exploration they discarded the use of cold water tubes in contact with the skin since participants found this unpleasant, drawing attention away from body-focusing.

In the language of our framework, this work focused on thermal cues in the *background* of the user's awareness: implementations which centred attention on the thermal cues were rejected since bodily awareness was the intended focus. Designs focused on a *single sensory modality* (thermal-haptic), and these thermal cues modulated affect by *prompting mindset* — supporting a calm focus on bodily awareness.

The design space in this work is largely structured in terms of implementation (ways of delivering thermal cues). Our framework points to an enriched design space, structured in terms of experiential properties, as articulated in Concept 1 (Section 5.1). C1.4 emphasises the importance of the *material quality* of the thermal cue: e.g. whether it is soft, sharp, enveloping, fluid, etc., influenced by a range of implementation parameters such as rate-of-change and the manner of contact with the body. Our framing points to alternative solutions to the finding that cold water tubes were unpleasant and captured attention: Different materials might have mediated the contact of the tube with the skin to make cold water stimulation more effective for the study's goals. Other material qualities might also have been explored: radiative directed sources (e.g. coolness from the Peltier effect) or warm airflow, supporting a more immersive, enveloping experience than possible with water tubes.

Our framework also emphasises the multisensory nature of thermal experience (Section 4.2,Section 5.2). Jonsson et al. only *explicitly* considered one sensory modality — thermal haptics. However, other sensory modalities, including other haptic dimensions will be implicitly present in the designs: the heat mat is soft, and the water tubes relatively rigid, for example. Again this framing clarifies differences between the sensory experience of the different delivery mechanisms. This also draws attention to the possibility of actuating other haptic dimensions alongside thermal haptics: e.g., by coordinating thermal cues with changes in material stiffness [e.g. 1], individual senses need not be so strongly stimulated and this may help guide bodily awareness rather than draw attention to the stimulus.

Finally, phases of the Feldenkrais exercise involve active physical movement, which will naturally generate bodily heat. In Concept 2, we pointed to the potential to design around internal, bodily, thermal experience (Section 5.2). While Jonsson et al. focused on a stationary part of the exercise, designers might also consider how thermal technologies might be used during active stages, to contrast or emphasise the heat generated by movement, e.g., via fabrics that vary in thermal conductivity in response to stretching and moisture [103].

6.2 Case 2 - Emotionally Resonant Haptics

Our second case study demonstrates the application of our framework to experimental user studies. Macdonald et al. investigated the effect of thermal cues on vibrotactile feedback. They identified fifteen patterns of "emotionally resonant haptics": vibrotactile feedback simulating sensations such as *cat purring*, *wind* and *underwater bubbles*. They identified an "expected temperature" for eight of these patterns leading them to expect that the impact of these patterns could be increased by simultaneously applying congruent thermal cues on the users' palms. For example, augmenting the *cat purring* pattern with warmth, and the *wind* pattern with cold. Their expectation was confirmed for just two of the fifteen stimuli: *Heartbeat* was resonant with warmth and dissonant with coldness, and *Small Stream* was resonant with coldness but dissonant with warmth.

In the language of our framework, this work explores *thermal imagery* (Section 4.1): the thermal associations are used to enrich a haptic experience, rather than being the focus of attention. In this, the approach is explicitly *multisensory*, and focuses on *synergy*: combining thermal and vibrotactile cues to create a unified experience. Thermal properties were discussed in terms of *intensity* or magnitude - warmth or coldness. The authors did not discuss their rationale for associating these intensities with the particular patterns of vibrotactile stimuli which they used to simulate *experiential qualities*.

Our framework can help bring greater richness and clarity to the space of possibility for such thermal augmentation. First, the aspects of thermal quality which we discuss under Concept 1 (Section 5.1) provide clarity in thinking about how thermal intensities transform into qualities like those targeted in the study. As we note in that section, cues of the same temperature can result in different affective and experiential outcomes, influenced by other details of the thermal cue and the context. In this study, for example, the same temperature range (34 °C) is combined with different vibrotactile patterns (which can be thought of in terms of simulated *material qualities*) to represent quite different sensations: *cat purring* and *heartbeat*. Another relevant design parameter, which could have been considered to increase *synergy* between thermal and haptic cues, is the *temporal* pattern of the thermal cues (Section 5.1 C1.2): For example, a thermal cue with a slower onset and dissipation may be more resonant with the quality of a cat purring, while a strong, active, pulsing warmth may be more resonant with the experiential quality of a Heartbeat.

Material qualities of the cues (C1.3) can also be considered here. Certain of the qualities targeted in the study had *immersive* associations (e.g. *wind*, *crashing waves*, *underwater bubbles*). Our framework suggests these could have been augmented by the use of immersive thermal delivery — such as a glove encompassing the hand, or thermal stimuli covering a larger area of the body. Meanwhile, smaller phenomena, which are commonly experienced by touch with a single hand, might be successfully augmented via point heat sources, in the manner described in the study. This seems to be reflected in the study's success in using the point heat sources to augment the *heartbeat* and *small stream* patterns. Future work may investigate this idea further.

Finally, designers may think in terms of the *perceived agency* of the thermal cues (Section 5.1 C1.4): the way cues can be perceived as more active or passive. Some phenomena targeted (e.g. *wind* and *crashing waves*) have an active character which might have been conveyed via sharp and sudden changes, implemented, for example, through a fast ramp-up to a cold thermal stimulus, and the use of materials with high thermal conductivity.

6.3 Case 3 - Thermal Customisation in Affective Regulation

Our third case study demonstrates how our framework can be applied to user studies and for thermal customisation. Umair et al. investigate user customisation of haptic patterns for personal affect regulation [94]. Using off-the-shelf, wrist-worn, thermal gadgets, they invited participants to customise the patterns of thermal stimulation to support affective regulation. Participants could choose the location of delivery (inside or outside of their wrists), and the intensity of the cue (ranging between -11°C to 16°C). Most participants chose the inner side of the wrist. Half chose temperatures in the "cool" range (-11°C to -8°C) and half chose the "hot" range (2°C to 10°C). It was found that user-designed thermal patterns helped participants deal with their stress regardless of the selected temperature range.

While this study emphasised the importance of experiential qualities in thermal customisation, in practice, participants articulated their experiences in a limited vocabulary, which concerned pleasantness, relaxation, and the magnitude of the thermal cue. This is understandable: it has been noted that qualities of bodily experience are difficult to articulate [73, p. 206]. Further, it seems likely that users' accounts of experience with thermal technologies may be shaped by experiences of commonplace everyday thermal technologies (e.g. thermostats), which generally emphasise intensity or magnitude. Such factors may limit the kinds of experiences and customisations which users describe, or imagine.

Our framework offers a route forward: providing an experience-centred set of vocabulary patterns (Section 4.1, summarised in Table 1), and qualities of thermal experience (Section 5.1) to specify greater nuance in thermal and affective experience. While the vocabulary data set is from Chinese, the patterns of articulation will be relevant to many languages (in this paper they have been articulated in English, for example). Researchers can draw upon these patterns to provide users with relevant exemplars and experiential qualities to scaffold their ability to articulate their own experiences and preferences. This can help users articulate their experiences in ways that go beyond simple magnitudes of temperature, to take in a richer range of experiential qualities, including valence, temporal and multisensory qualities, the sense of activeness or passiveness, etc. Since these vocabularies map closely to the qualities articulated in Section 5.1, this can support participatory design processes, and intuitive, experience-centred customisation.

Further, in cases like this, where design focuses on emotional regulation, the different relationships between thermal and affective experience which we articulate in Concept 3 (Section 5.3.1) will be relevant. Psychological research emphasises that modulation of affective response, modulation of attention, and reflection occur in different phases of emotional regulation [35]. Thus, it will be helpful to distinguish between approaches which aim to use thermal experience to *induce* affect or *modulate* existing affect, and cases where thermal experiences *support reflection* on the users' experiences, or promote a particular *mindset.* Thermal cues designed for the "attentional deployment" phase, may aim to guide attention during an emotional episode. This is likely to require a different approach than the design of cues for "response modulation": e.g. promoting reflection after an emotional episode.

7 DISCUSSION

7.1 An Experience-Centred Framework for Thermal Design

This is not the first framework to address haptic and thermal technologies in general. In haptics, researchers have developed vocabularies to help communicate and describe tactile experience [66, 69], begun the work required to translate between engineering parameters and experiential descriptions [77], and articulated research agendas for haptic-affective design [e.g., 57]. In such work, however, thermal interaction is rarely a major focus. Meanwhile, work with a more substantial focus on thermal interaction tends to be narrowly scoped: restricted, for example, to thermal comfort in architecture [4, 24], or technical details of thermal cues in AR [71]. As such there is a lack of integrative work which can furnish language and concepts to help designers describe, frame, and conceptualise the complex multisensory design space for thermal and affective interaction.

In this paper, we set out to address this by analysing accounts of thermal and affective experience in a literature renowned for its careful description of experience. Our framework draws from poetic description, but, as shown in our case studies, we identify principles and concepts which bring clarity to issues in contemporary work on thermal interaction. This effort overlaps somewhat with previous research in thermal-interaction [e.g. 38, 56, 99] in addressing psychological concepts like the affective circumplex [75]. However, we articulate concepts, vocabulary, and principles that go far beyond those identified in previous work, including temporal, material and multisensory qualities of thermal experience. These provide a richer and more nuanced vocabulary which designers can use to frame and communicate their investigations, clarify hypotheses, and support users in articulating their experiences and preferences.

An important aspect of our results is that they foreground how relationships between thermal and affective qualities can be sensitive to context and culture. This is consistent with previous findings about the context-specificity of crossmodal and thermal associations [e.g. 18, 62, 96], but contrasts with previous thermal-interaction research. It raises the question of how to ground thermal-affective design in a richer, situated, account of experience.

Our framework addresses this in two ways. First, to support the articulation of qualitative thermal experience, we identify patterns of vocabulary which support the nuanced expression of thermal and thermal-affective experience. This can support designers in discussing design spaces, identifying relevant features, and eliciting more detailed reports from users. Second, we both expand and clarify the design space for thermal and thermal-affective design, refocusing this on experiential qualities. We move beyond the search for simple and consistent mappings between thermal perception and affective categories, identifying three key concepts which can guide attention to greater nuance in the ways thermal cues influence thermal and affective experience. In doing so, we draw attention to features neglected in previous research on thermal-affective design, such as the multisensory nature of thermal cues, their unfolding over time, and the different ways thermal and affective experience influence each other. An important aspect of our approach is that, by placing experience first, we avoid constraint by the current limitations of thermal actuators. The content of our framework can continue to guide design as technological means expand, while itself being clarified and expanded by future research on thermal and affective perception (see Section 7.2, below).

Our three design cases demonstrate the ability of the framework to enrich design spaces, bring clarity to the analysis of emotionally rich haptics, and provide structure for users to articulate experience and specify desired qualities. Beyond these three examples, we see the potential for the concepts and vocabularies we identify to support ideation, research through design, and co-design. Our results also raise open questions for future empirical work on thermal and thermal-affective perception (below Section 7.2).

Finally, we see contributions beyond thermal experience design: First, some principles we identify are relevant to design in other sensory modalities such as smell [14, 17], haptics [46, 57] and sound [31]. Examples of this include the transformation of magnitude into quality, the role of temporality in sensory cues and experiences, and the attribution of agency to these cues. Second, our use of lexical analysis provides a template for a range of future work. The rich accounts of situated experience found in literary works can enrich understandings of perception and experience in a range of interaction domains, in ways not possible in experimental studies.

7.2 Open Questions and Future Work

Some open questions raised by our work were articulated in our presentation of the design framework. We noted, for example, that future work should seek to understand how and when thermal contrast can intensify experience (Section 5.2), and clarify the boundary conditions for stable thermal-affective associations (the conditions under which e.g. coldness is associated with high arousal alertness) (Section 5.3.2). Below we outline further open questions which may be addressed in future work.

First, our results emphasise that perception never occurs in isolation. As such it is important to understand how cues across multiple sensory modalities integrate together, contrast, or substitute for one another. Previously, thermal research in HCI has focused almost exclusively on the haptic modality, at the expense of other sensory modalities which convey thermal experience [56, 94, 99]. Our work points beyond this: to the potential for future work to investigate how multisensory synergies can support rich thermal and thermal-affective experience, and how it can renew awareness of cues. Future research on cross-sensory thermal perception might clarify this through a range of research methods, including interviews, participatory design, and in-the-wild studies. Such work may draw on the suggestions we make in Section 5.2, as well as research in sensory psychology [e.g., 83] in specifying hypotheses. However, we suggest design research should push beyond the strictly controlled and generally non-interactive conditions of most psychological research, to develop ecological understandings adequate to everyday conditions of interaction [29, 50].

Second, in our design framework we took beginning steps to translate rich and complex descriptions of experience into design concepts and principles. Future research should seek to extend this framework by translating subjective experience and thermal features into the language of engineering: formal descriptors and parameters that can serve the needs of technical implementation. In its current form, the framework does not speak to these issues — we intentionally took an experience-centred approach to avoid constraint by current technical limitations and framings. In developing such implementation vocabularies, future work may be guided by relevant previous research on technical mappings in haptics [e.g. 46, 66, 77].

Third, we have outlined different ways in which thermal cues can impact affective experience and vice versa. For example: does the application of thermal cues *induce* particular affective states, *amplify* or *dampen* the intensity of affective states, *guide attention*, or *support reflection* or a particular *mindset*? Such distinctions have not been addressed in previous work, yet we suggest they will be important in the design of consistent and reproducible thermal affective experiences and in addressing the different stages of emotional regulation [see, e.g. 35]. Several parts of our design framework provide starting points for such work in future (e.g. Section 5.3).

Fourth, design experimentation will be necessary to develop understandings of thermal-affective interaction. To support this, it will be important to bridge the gap between thermal prototyping and experience-centred approaches. In other design areas, including haptic design [63, 64], sketch prototyping approaches are common in ideation and prototyping [27, 79]. Future work may develop a thermal toolkit to support such prototyping and may be guided by the concepts articulated in our framework.

Fifth, it is important to note that while our analysis draws on scientific, psychological terms — particularly "multisensory", and "crossmodal" — our results should not be read as confirmatory scientific results. Our work is theoretical and exploratory, mapping a space for future work and hypotheses rather than providing evidence for existing hypotheses. Our use of scientific terms aims to draw connections to established programmes in sensory psychology [e.g. 84, 85], helping to link our concepts to previous empirical findings [e.g. 29, 50], and support future hypothesis generation.

Finally, this paper counterbalances the dominant focus on European and American cultures in previous sensory-affective research. Future work may continue along this path by drawing on art, literature, and other sources of human experience, from a variety of languages and cultures. The contribution of such work goes beyond inclusion and can enrich and clarify experiential constructs in European languages [54, 55]. We discuss this further in the next section.

7.3 Reflections on Choice of Texts

In this section we reflect on how the particularities of our corpus influence our results, and on opportunities for future researchers to further expand the framework by drawing on other authors and literary cultures.

We have noted the aptness of Cí poetry as a source for designing sensory and affective experiences (see Section 2.3). Among other qualities, Cí emphasises concrete description of first-person experience and the natural world [8, 42, 104]. Lǐ Qīng Zhào and Sū Shì in particular are celebrated for their sensitivity to the ways in which human experience is entangled with the material qualities and processes of the non-human world [42, 101]: In their descriptions the subject "becomes part of and in effect empathizes with" the natural context [42, p.315]. In our framework we are aware that these qualities have led to a foregrounding of the materiality and perceived agency of thermal qualities, and attention to the multisensory complexity of thermal experience in lived contexts.

While some of the examples in our results contain culturally or geographically specific elements, our results are not limited to the specificities of one time and place. We have taken care to extract more general principles from these specific accounts. Nonetheless, particular authors and literatures inevitably focus on particular qualities and perspectives. In future work, we see the potential to augment our framework with analysis of other literatures or authors, foregrounding different qualities and principles.

The potential here can be illustrated by comparing Cí with English romantic poetry. While both forms are strongly concerned with nature and experience [87, 90], their perspectives differ starkly [90]. As we note above, Cí poets like Lǐ Qīng Zhào and Sū Shì present an integrated view of individual experience embedded in the natural world [42, 101]. By contrast, it has been argued that English romantic poets depict a "deep dichotomy between human beings and nature" [90, p. 343], often addressing nature as an object of distant or sublime contemplation, or as a "vehicle" to express the artist's inner experience [90, p. 343]. Importantly, this difference in attitude may even influence how basic material qualities are represented [101]. In the work of writers like Sū Shì, objects and phenomena generally retain their natural physicality: Water, for example, flows, reacts to light, and generally behaves as physical water does, and the writer's artistry consists in a careful framing of these qualities to express and illuminate their experience and ideas [101, p. 534]. By contrast, Wu argues, European romantic poets transform the material properties of the natural world far more freely. Description is often detached from physical constraints to suit the expression of the self and the flight of the poetic imagination [101, p. 523]. In Coleridge's *Rime of the Ancient Mariner*, for example, water loses its familiar nature and is "transfigured into a witch's burning, slimy oil" [101, p. 523].

As such, while analysis of Cí poetry may help designers in "the act of listening to and thinking with things" [101, p. 537], we suggest that analysis of European romantic poetry might foreground more exotic and fantastical imagery. This may, for example, furnish additional material for expressive and escapist scenarios[9].

Readers will no doubt identify opportunities to draw on other cultures for their distinctive contributions. We see value in addressing a range of literary cultures: both to expand the framework articulated in this paper and to address other aspects of experience in interactive design. In particular, our own corpus contained relatively few experiences of shared or communal sensory experiences. There may be value in future work addressing literary and artistic cultures which emphasise these situations.

7.4 Reflections on Translation

As we note in Section 2.1 cross-cultural research is not only a corrective to redress deficits of inclusion. It also has a positive, generative value. Benjamin articulates this generative value in terms of the excess of "sense" found in each language culture [11]. The simplest kind of translation involves finding the words in two different languages which pick out the "same" object, concept, or state of affairs: I point and say "火烧", while you point and say "bread" (or "brot", "pain", ...). However, even when they pick out precisely the same object, words in different languages will carry different *senses* [11, p. 74]: different networks of associations, allusions, and entanglements with tradition. Translation is generative when it brings these different networks of sense into contact with one-another: "expanding and deepening [one] language by means of the foreign language" [11, p. 81]. Similar ideas are found in psychological uses of lexical analysis to enrich experiential constructs [e.g. 54, 55], where translation is seen as transmitting "living characteristic of a given society, [and its] ways of thinking" [p. 5 97]

A consequence of this is that no translation can be final. Each will give a particular perspective on the networks of sense around the text, relative to a particular translator, with a particular purpose, at a particular time in history [11, p. 73]. The translations in our paper were made by the first author — a native speaker of Chinese, with an educational background in industrial design, cognitive science and HCI. Chinese classical poetry has been an important part of her life since childhood. For the translations in this paper, her goal was to convey the sensory and affective experience of the original texts. When selecting between alternative linguistic solutions, these issues and influences took precedence, over fluency, rhyme, and a range of allusions and implications which seemed less relevant to our concern with the design of sensory technologies.

To illustrate the tensions and decisions in translation, consider the poem in Figure 2, and its alternative translation by Egan (see footnote 1). This poem refers to a heavy 花钿 "huā diàn" — a decoration worn between one's eyebrows. The heaviness of the "huā

[9]It is important to note the risk of essentialising differences between Chinese and European literatures. We emphasise that this paragraph concerns *tendencies* in particular traditions in each cultures. Chinese literature also contains much fantastic imagery for example [101]

diàn" carries embodied-affective connotations, implying the narrator's frown, but there is no widely recognised equivalent word in English. As such the first author opted to use a romanisation of the word and explain its meaning in a footnote. This sacrifices elegance and immediacy in order to convey embodied-affective connotations — an acceptable trade-off given the goals of the paper. By contrast, Egan translates "huā diàn" as "hair clasp", losing the affective connotation. While he does not comment on this choice, it seems to prioritise elegance and accessibility over affective connotations. Perhaps the gendered nature of the "huā diàn" is relevant: the affective connotations of its heaviness may be more easily overlooked by those less accustomed to wearing make-up.

8 CONCLUSION

Interest in thermal experience in technology interaction has grown in recent years. However, the field stills lacks vocabulary to discuss and conceptualise the rich and nuanced associations possible between thermal perception and affective experience. To address this, we analysed a corpus of Chinese classical *Cí* poetry — a form celebrated for its ability to convey subjective, embodied and environmentally situated experience. In doing so, we identified patterns of vocabulary which can support designers and researchers in articulating thermal and thermal-affective experiences, and to characterise factors which influence this experience. Based on our findings, we further propose a framework for thermal and thermal-affective experience design which spotlights three key concepts: the experiential qualities of thermal experience, the multisensory nature of thermal cues, and the synergies and associations linking thermal and affective experience. This framework takes steps towards a more ecological and meaningful understanding of thermal-affective experience, providing resources and open questions for future work in this area.

ACKNOWLEDGMENTS

I would like to thank Mrs Li Ping for opening the gates of literature appreciation with her beautiful voice and keen observations in daily life. I would also like to thank Prof. Wang Bing Fu from the School of Literature, History and Philosophy of Shandong University for his guidance, encouragement and suggestions on poetry translation.

Funded by the European Union (ERC, THEORYCRAFT, 101043198). Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the European Research Council Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

REFERENCES

[1] Ahmed Al Maimani and Anne Roudaut. 2017. Frozen suit: designing a changeable stiffness suit and its application to haptic games. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, Denver Colorado, 2440–2448.

[2] Liliana Albertazzi, Michela Malfatti, Luisa Canal, and Rocco Micciolo. 2015. The Hue of Angles — Was Kandinsky Right? *Art & Perception* 3, 1 (Jan. 2015), 81–92. https://doi.org/10.1163/22134913-00002025 Publisher: Brill.

[3] Adriana Alvarado Garcia, Juan F. Maestre, Manuhuia Barcham, Marilyn Iriarte, Marisol Wong-Villacres, Oscar A Lemus, Palak Dudani, Pedro Reynolds-Cuéllar, Ruotong Wang, and Teresa Cerratto Pargman. 2021. Decolonial Pathways: Our Manifesto for a Decolonizing Agenda in HCI Research and Design. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems (CHI EA '21)*. Association for Computing Machinery, New York, NY, USA, 1–9. https://doi.org/10.1145/3411763.3450365

[4] Eleni Ampatzi, Despoina Teli, and Marcel Schweiker. 2020. On the linguistic challenges of cross-national research in thermal comfort: The effects of language choices in Greek and Swedish thermal perception questionnaires used in two large-scale surveys conducted two decades apart. In *Proceedings of Windsor 2020 Resilient comfort*. The Windsor Conference, Windsor, 367–380.

[5] ASHRAE and the American National Standards Institute. 2017. *ANSI/ASHRAE Standard 55-2017*. American National Standards Institute. https://www.ashrae.org/file%20library/technical%20resources/standards%20and%20guidelines/standards%20addenda/55_2017_d_20200731.pdf

[6] Albert Atkin. 2005. Peirce on the Index and Indexical Reference. *Transactions of the Charles S. Peirce Society* 41, 1 (2005), 161–188. https://www.jstor.org/stable/40358956 Publisher: Indiana University Press.

[7] Francisco Barbosa Escobar, Carlos Velasco, Kosuke Motoki, Derek Victor Byrne, and Qian Janice Wang. 2021. The temperature of emotions. *PloS one* 16, 6 (2021), e0252408.

[8] Ye Mengde (叶梦得). 2018. *Bi Shu Lu Hua (避暑录话)*. Shandong People's Publishing House (山东人民出版社), Jinan.

[9] Zhou Duwen (周笃文). 1980. *Cí poetry (宋词)*. Shanghai Classics Publishing House (上海古籍出版社), Shanghai.

[10] Li Qingzhao (李清照). 2019. *Complete collection of Li Qingzhao's poems (李清照诗词全集)*. CITIC Publishing Group (中信出版集团), Beijing.

[11] Walter Benjamin. 1999. The task of the translator: An introduction to the translation of Baudelaire's Tableaux Parisiens. In *Illuminations*. Pimlico, London, 70–83.

[12] Margaret M Bradley and Peter J Lang. 1999. *Affective norms for English words (ANEW): Instruction manual and affective ratings*. Technical Report. Technical report C-1, the center for research in psychophysiology ….

[13] Virginia Braun and Victoria Clarke. 2021. Can I use TA? Should I use TA? Should I not use TA? Comparing reflexive thematic analysis and other pattern-based qualitative analytic approaches. *Counselling and Psychotherapy Research* 21, 1 (2021), 37–47. https://doi.org/10.1002/capr.12360 _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/capr.12360.

[14] Jas Brooks, Pedro Lopes, Judith Amores, Emanuela Maggioni, Haruka Matsukura, Marianna Obrist, Roshan Lalintha Peiris, and Nimesha Ranasinghe. 2021. Smell, taste, and temperature interfaces. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. ACM, Yokohama, Japan, 1–6.

[15] Jas Brooks, Steven Nagels, and Pedro Lopes. 2020. Trigeminal-based temperature illusions. In *Proceedings of the 2020 CHI conference on human factors in computing systems*. ACM, Honolulu Hawaii, 1–12.

[16] Cesar Flores Cano and Anne Roudaut. 2019. MorphBenches: Using mixed reality experimentation platforms to study dynamic affordances in shape-changing devices. *International Journal of Human-Computer Studies* 132 (Dec. 2019), 1–11. https://doi.org/10.1016/j.ijhcs.2019.07.006

[17] Patricia Cornelio, Emanuela Maggioni, Giada Brianza, Sriram Subramanian, and Marianna Obrist. 2020. SmellControl: the study of sense of agency in smell. In *Proceedings of the 2020 International Conference on Multimodal Interaction*. ACM, Netherlands, 470–480.

[18] Nur Dalilah Dahlan and Yakubu Yau Gital. 2016. Thermal sensations and comfort investigations in transient conditions in tropical office. *Applied Ergonomics* 54 (May 2016), 169–176. https://doi.org/10.1016/j.apergo.2015.12.008

[19] Claudia Daudén Roquet and Corina Sas. 2021. Interoceptive interaction: An embodied metaphor inspired approach to designing for meditation. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. ACM, Yokohama, Japan, 1–17.

[20] Sophie David. 2002. Linguistic expressions for odors in French. *Olfaction, taste and cognition* (2002), 82–99. https://books.google.com/books?hl=en&lr=&id=Zpc2HbWbgTIC&oi=fnd&pg=PA82&dq=Linguistic+expressions+of+odors+in+French&ots=STZctkSJa7&sig=Fv3uRCrMAZiHpuP0Hyo4PIf8eLU Publisher: Cambridge University Press, Cambridge.

[21] Sebastian Deterding. 2016. Contextual Autonomy Support in Video Game Play: A Grounded Theory. In *CHI '16: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM Press, San Jose, California, USA, 3931–3943. https://doi.org/10.1145/2858036.2858395

[22] Camilla Di Biase-Dyson and Gaëlle Chantrain. 2021. Metaphors of sensory experience in ancient Egyptian texts: Emotion, personality, and social interaction. In *The Routledge Handbook of the Senses in the Ancient Near East*. Routledge, 603–635.

[23] Nicola Di Stefano, Maddalena Murari, and Charles Spence. 2022. Crossmodal Correspondences in Art and Science: Odours, Poetry, and Music. In *Olfaction: An Interdisciplinary Perspective from Philosophy to Life Sciences*, Nicola Di Stefano and Maria Teresa Russo (Eds.). Springer International Publishing, Cham, 155–189. https://doi.org/10.1007/978-3-030-75205-7_10

[24] Noël Djongyang, René Tchinda, and Donatien Njomo. 2010. Thermal comfort: A review paper. *Renewable and sustainable energy reviews* 14, 9 (2010), 2626–2640.

[25] Ronald Egan. 2019. *The Works of Li Qingzhao.* Walter de Gruyter GmbH & Co KG, Berlin.

[26] Ronald Egan. 2020. *Word, Image, and Deed in the Life of Su Shi.* BRILL, Leiden.

[27] JJ Eissen and GNRE Steur. 2008. *Sketching, drawing techniques for product designers.* Laurence King Publishing, London.

[28] Abdallah El Ali, Xingyu Yang, Swamy Ananthanarayan, Thomas Röggla, Jack Jansen, Jess Hartcher-O'Brien, Kaspar Jansen, and Pablo Cesar. 2020. ThermalWear: Exploring wearable on-chest thermal displays to augment voice messages with affect. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing systems.* ACM, Honolulu Hawaii, 1–14.

[29] Feng Feng, Dan Bennett, Zhi-jun Fan, and Oussama Metatla. 2022. It's Touching: Understanding Touch-Affect Association in Shape-Change with Kinematic Features. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems.* ACM, New Orleans, LA, 1–18.

[30] Christopher Frauenberger. 2019. Entanglement HCI The Next Wave? *ACM Transactions on Computer-Human Interaction* 27, 1 (Nov. 2019), 2:1–2:27. https://doi.org/10.1145/3364998

[31] Emma Frid, Hans Lindetorp, Kjetil Falkenberg Hansen, Ludvig Elblaus, and Roberto Bresin. 2019. Sound forest: evaluation of an accessible multisensory music installation. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems.* ACM, Glasgow, 1–12.

[32] Michael Fuller. 2020. *An introduction to Chinese poetry: from the Canon of poetry to the lyrics of the Song dynasty.* Brill, Leiden.

[33] Michael Anthony Fuller. 2017. *An introduction to Chinese poetry: from the canon of poetry to the lyrics of the Song dynasty.* Number 408 in Harvard East Asian monographs. Harvard University Asia Center, Cambridge, Massachusetts.

[34] Emily L Graczyk, Benoit P Delhaye, Matthew A Schiefer, Sliman J Bensmaia, and Dustin J Tyler. 2018. Sensory adaptation to electrical stimulation of the somatosensory nerves. *Journal of neural engineering* 15, 4 (2018), 046002.

[35] James J Gross. 2015. Emotion regulation: Current status and future prospects. *Psychological inquiry* 26, 1 (2015), 1–26.

[36] Steve Guest, Jean Marc Dessirier, Anahit Mehrabyan, Francis McGlone, Greg Essick, George Gescheider, Anne Fontana, Rui Xiong, Rochelle Ackerley, and Kevin Blot. 2011. The development and validation of sensory and emotional scales of touch perception. *Attention, Perception, & Psychophysics* 73 (2011), 531–550.

[37] Tang Gui Zhang. 1965. *The collection of Cí poetry in Song dynasty.* Zhonghua Book Company, Hong Kong.

[38] Luke Haliburton, Svenja Yvonne Schött, Linda Hirsch, Robin Welsch, and Albrecht Schmidt. 2023. Feeling the Temperature of the Room: Unobtrusive Thermal Display of Engagement during Group Communication. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 7, 1 (2023), 1–21.

[39] Yan He, George Chernyshov, Jiawen Han, Dingding Zheng, Ragnar Thomsen, Danny Hynds, Muyu Liu, Yuehui Yang, Yulan Ju, Yun Suen Pai, et al. 2022. Frisson waves: exploring automatic detection, triggering and sharing of aesthetic chills in music performances. *Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* 6, 3 (2022), 1–23.

[40] Joseph Henrich, Steven J Heine, and Ara Norenzayan. 2010. Most people are not WEIRD. *Nature* 466, 7302 (2010), 29–29.

[41] Hsin-Ni Ho, Daisuke Iwai, Yuki Yoshikawa, Junji Watanabe, and Shin'ya Nishida. 2014. Combining colour and temperature: A blue object is more likely to be judged as warm than a red object. *Scientific reports* 4, 1 (2014), 5527.

[42] Peter I-min Huang. 2021. Li Qingzhao and Ecofeminism: Body and Language. *ISLE: Interdisciplinary Studies in Literature and Environment* 28, 1 (2021), 312–328.

[43] Abhinandan Jain, Felix Schoeller, Emilie Zhang, and Pattie Maes. 2022. Frisson: Leveraging metasomatic interactions for generating aesthetic chills. In *Proceedings of the 2022 International Conference on Multimodal Interaction.* ACM, Bangalore, India, 148–158.

[44] Martin Jonsson, Anna Ståhl, Johanna Mercurio, Anna Karlsson, Naveen Ramani, and Kristina Höök. 2016. The aesthetics of heat: guiding awareness with thermal stimuli. In *Proceedings of the TEI'16: Tenth International Conference on Tangible, Embedded, and Embodied Interaction.* ACM, Eindhoven, 109–117.

[45] Camille L Kapaun and Robin Dando. 2017. Deconvoluting physical and chemical heat: Temperature and spiciness influence flavor differently. *Physiology & behavior* 170 (2017), 54–61.

[46] Erin Kim and Oliver Schneider. 2020. Defining haptic experience: foundations for understanding, communicating, and evaluating HX. In *Proceedings of the 2020 CHI conference on human factors in computing systems.* ACM, Honolulu Hawaii, 1–13.

[47] Jungsoo Kim, Jihye Ryu, Bongchan Jeong, and Richard de Dear. 2022. Semantic discrepancies between Korean and English versions of the ASHRAE sensation scale. *Building and Environment* 221 (2022), 109343.

[48] Shaimaa Lazem, Danilo Giglitto, Makuochi Samuel Nkwo, Hafeni Mthoko, Jessica Upani, and Anicia Peters. 2022. Challenges and Paradoxes in Decolonising HCI: A Critical Discussion. *Computer Supported Cooperative Work (CSCW)* 31, 2 (June 2022), 159–196. https://doi.org/10.1007/s10606-021-09398-0

[49] Wonjun Lee and Youn-kyung Lim. 2010. Thermo-message: exploring the potential of heat as a modality of peripheral expression. In *CHI'10 Extended Abstracts on Human Factors in Computing Systems.* ACM, Atlanta, 4231–4236.

[50] Anan Lin, Meike Scheller, Feng Feng, Michael J Proulx, and Oussama Metatla. 2021. Feeling colours: crossmodal correspondences between tangible 3D objects, colours and emotions. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* ACM, Yokohama, Japan, 1–12.

[51] Henry WJ Lin, David James Barter, and Ron Wakkary. 2013. Patterns of experience in thermal conceptual metaphors. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems.* ACM, Paris, 1743–1748.

[52] Sebastian Linxen, Christian Sturm, Florian Brühlmann, Vincent Cassau, Klaus Opwis, and Katharina Reinecke. 2021. How weird is CHI?. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* ACM, Yokohama, Japan, 1–14.

[53] Yuhu Liu, Satoshi Nishikawa, Young Ah Seong, Ryuma Niiyama, and Yasuo Kuniyoshi. 2021. ThermoCaress: A wearable haptic device with illusory moving thermal stimulation. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* ACM, Yokohama, Japan, 1–12.

[54] Tim Lomas. 2016. Towards a positive cross-cultural lexicography: Enriching our emotional landscape through 216 'untranslatable'words pertaining to well-being. *The Journal of Positive Psychology* 11, 5 (2016), 546–558.

[55] Tim Lomas. 2022. The appeal of aesthetics: A cross-cultural lexical analysis. *Psychology of Aesthetics, Creativity, and the Arts* 17, 4 (2022), 518–529.

[56] Shaun Alexander Macdonald, Frank Pollick, and Stephen Anthony Brewster. 2022. The Impact of Thermal Cues on Affective Responses to Emotionally Resonant Vibrations. In *Proceedings of the 2022 International Conference on Multimodal Interaction.* ACM, Bangalore, India, 259–269.

[57] Karon E MacLean. 2022. Designing affective haptic experience for wellness and social communication: where designers need affective neuroscience and psychology. *Current Opinion in Behavioral Sciences* 45 (2022), 101113.

[58] Lawrence E. Marks. 1975. On colored-hearing synesthesia: cross-modal translations of sensory dimensions. *Psychological bulletin* 82, 3 (1975), 303. Publisher: American Psychological Association.

[59] Lawrence E. Marks. 1982. Synesthetic perception and poetic metaphor. *Journal of Experimental Psychology: Human Perception and Performance* 8, 1 (1982), 15. Publisher: American Psychological Association.

[60] Louise Petersen Matjeka and Florian'Floyd' Mueller. 2020. Designing for Bodily Play Experiences Based on Danish Linguistic Connotations of" Playing a Game". In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play.* ACM, Ottowa, Canada, 19–31.

[61] Oussama Metatla, Emanuela Maggioni, Clare Cullen, and Marianna Obrist. 2019. " Like Popcorn" Crossmodal Correspondences Between Scents, 3D Shapes and Emotions in Children. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems.* ACM, Glasgow, 1–13.

[62] Kosuke Motoki, Toshiki Saito, and Carlos Velasco. 2022. Spontaneous crossmodal correspondences grounded in contexts. *Food Quality and Preference* 100 (Sept. 2022), 104619. https://doi.org/10.1016/j.foodqual.2022.104619

[63] Camille Moussette and Richard Banks. 2010. Designing through making: exploring the simple haptic design space. In *Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction.* ACM, Cambridge, Mass., 279–282.

[64] Camille Moussette and Fabricio Dore. 2010. Sketching in Hardware and Building Interaction Design: Tools, Toolkits and an Attitude for Interaction Designers. In *Design and Complexity - DRS International Conference.* Design Research Society, London, 16 pages.

[65] Florian'Floyd' Mueller, Louise Matjeka, Yan Wang, Josh Andres, Zhuying Li, Jonathan Marquez, Bob Jarvis, Sebastiaan Pijnappel, Rakesh Patibanda, and Rohit Ashok Khot. 2020. " Erfahrung & Erlebnis" Understanding the Bodily Play Experience through German Lexicon. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction.* ACM, Sydney Australia, 337–347.

[66] Marianna Obrist, Sue Ann Seah, and Sriram Subramanian. 2013. Talking about tactile experiences. In *Proceedings of the SIGCHI conference on human factors in computing systems.* ACM, Paris, 1659–1668.

[67] ISO/TC 159/SC 5 Ergonomics of the physical environment. 2019. *ISO 10551:2019.* International Standards Organisation. https://www.iso.org/standard/67186.html

[68] MICHAEL O'MAHONY. 1986. Sensory adaptation. *Journal of Sensory Studies* 1, 3-4 (1986), 237–258.

[69] Sharon Oviatt, Björn Schuller, Philip Cohen, Daniel Sonntag, and Gerasimos Potamianos. 2017. *The handbook of multimodal-multisensor interfaces, volume 1: Foundations, user modeling, and common modality combinations.* Morgan & Claypool, San Rafael.

[70] Stephen Owen. 2020. *Just a song: Chinese lyrics from the eleventh and early twelfth centuries.* BRILL, Leiden.

[71] Kaushik Parida, Hyunwoo Bark, and Pooi See Lee. 2021. Emerging thermal technology enabled augmented reality. *Advanced Functional Materials* 31, 39 (2021), 2007952.

[72] Cesare V Parise and Charles Spence. 2012. Audiovisual crossmodal correspondences and sound symbolism: a study using the implicit association test. *Experimental Brain Research* 220 (2012), 319–333.
[73] Zdravko Radman. 2012. *Knowing without thinking: mind, action, cognition and the phenomenon of the background.* Springer, New York.
[74] Neil Roberts (Ed.). 2003. *A Companion to Twentieth-Century Poetry* (1 ed.). Wiley, Hoboken, NJ. https://doi.org/10.1002/9780470998670
[75] James A. Russell. 1980. A circumplex model of affect. *Journal of personality and social psychology* 39, 6 (1980), 1161. https://psycnet.apa.org/journals/psp/39/6/1161/ Publisher: American Psychological Association.
[76] Oliver Schneider, Karon MacLean, Colin Swindells, and Kellogg Booth. 2017. Haptic experience design: What hapticians do and where they need help. *International Journal of Human-Computer Studies* 107 (Nov. 2017), 5–21. https://doi.org/10.1016/j.ijhcs.2017.04.004
[77] Oliver S Schneider, Hasti Seifi, Salma Kashani, Matthew Chun, and Karon E MacLean. 2016. HapTurk: Crowdsourcing affective ratings of vibrotactile icons. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems.* ACM, San Jose, 3248–3260.
[78] Hasti Seifi, Kailun Zhang, and Karon E MacLean. 2015. VibViz: Organizing, visualising and navigating vibration libraries. In *2015 IEEE World Haptics Conference (WHC).* IEEE, New York, 254–259.
[79] James A Self. 2019. Communication through design sketches: Implications for stakeholder interpretation during concept design. *Design Studies* 63 (2019), 1–36.
[80] Poppy Siahaan. 2022. Indonesian basic olfactory terms: more negative types but more positive tokens. *Cognitive Linguistics* 33, 3 (2022), 447–480.
[81] Charles Spence. 2011. Crossmodal correspondences: A tutorial review. *Attention, Perception, & Psychophysics* 73 (2011), 971–995.
[82] Charles Spence. 2015. Multisensory Flavor Perception. *Cell* 161, 1 (March 2015), 24–35. https://doi.org/10.1016/j.cell.2015.03.007
[83] Charles Spence. 2020. Temperature-based crossmodal correspondences: Causes and consequences. *Multisensory Research* 33, 6 (2020), 645–682.
[84] Charles Spence. 2022. Exploring group differences in the crossmodal correspondences. *Multisensory Research* 35, 6 (2022), 495–536.
[85] Charles Spence. 2022. Multisensory contributions to affective touch. *Current Opinion in Behavioral Sciences* 43 (2022), 40–45.
[86] Charles Spence and Jon Driver. 1997. Audiovisual links in exogenous covert spatial orienting. *Perception & psychophysics* 59, 1 (1997), 1–22.
[87] Joshua Stanley. 2021. J.H. Prynne's romanticism: Wordsworth and the dawn of neoliberalism. *Textual Practice* 35, 7 (July 2021), 1087–1108. https://doi.org/10.1080/0950236X.2020.1731586
[88] Erik Stolterman and Mikael Wiberg. 2010. Concept-driven interaction design research. *Human–Computer Interaction* 25, 2 (2010), 95–118.
[89] Corbin & Strauss. 2015. Basics of qualitative research: Techniques and procedures for developing grounded theory 4th Edition. (2015).
[90] Cecile Chu—chin Sun. 2006. Mimesis and Xing, Two Modes of Viewing Reality: Comparing English and Chinese Poetry. *Comparative Literature Studies* 43, 3 (2006), 326–354.
[91] Cecile CC Sun. 2020. *Pearl from the Dragon's Mouth: Evocation of Scene and Feeling in Chinese Poetry.* University of Michigan Press, Michigan.
[92] Paul Tennent, Kristina Höök, Steve Benford, Vasiliki Tsaknaki, Anna Ståhl, Claudia Dauden Roquet, Charles Windlin, Pedro Sanches, Joe Marshall, Christine Li, et al. 2021. Articulating soma experiences using trajectories. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems.* ACM, Yokohama, Japan, 1–16.
[93] Jordan Tewell, Jon Bird, and George R Buchanan. 2017. The heat is on: A temperature display for conveying affective feedback. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems.* ACM, Denver, Colorado, 1756–1767.
[94] Muhammad Umair, Corina Sas, Niaz Chalabianloo, and Cem Ersoy. 2021. Exploring personalized vibrotactile and thermal patterns for affect regulation. In *Designing Interactive Systems Conference 2021.* ACM, Nowhere and Everywhere, 891–906.
[95] Francisco J Varela and Jonathan Shear. 1999. First-person methodologies: What, why, how. *Journal of Consciousness studies* 6, 2-3 (1999), 1–14.
[96] K. B. Velt and H. A. M. Daanen. 2017. Thermal sensation and thermal comfort in changing environments. *Journal of Building Engineering* 10 (March 2017), 42–46. https://doi.org/10.1016/j.jobe.2017.02.004
[97] Anna Wierzbicka. 1997. *Understanding cultures through their key words: English, Russian, Polish, German, and Japanese.* Vol. 8. Oxford University Press, Oxford.
[98] Graham Wilson and Stephen A Brewster. 2017. Multi-moji: Combining thermal, vibrotactile & visual stimuli to expand the affective range of feedback. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems.* ACM, Denver Colorado, 1743–1755.
[99] Graham Wilson, Dobromir Dobrev, and Stephen A Brewster. 2016. Hot under the collar: Mapping thermal feedback to dimensional models of emotion. In *proceedings of the 2016 CHI conference on human factors in computing systems.* ACM, San Jose, California, 4838–4849.
[100] Ewelina Wnuk and Yuma Ito. 2021. The heart's downward path to happiness: Cross-cultural diversity in spatial metaphors of affect. *Cognitive Linguistics* 32, 2 (2021), 195–218.
[101] Tsaiyi Wu. 2020. Chinese Thing-Metaphor: Translating Material Qualities to Spiritual Ideals. *Philosophy East and West* (2020), 522–542.
[102] Ming Xie. 2021. *Ezra Pound and the Appropriation of Chinese Poetry: Cathay, Translation, and Imagism.* Routledge, London. Google-Books-ID: Tp-tIEAAAQBAJ.
[103] Xiaohui Zhang, Xujiang Chao, Lun Lou, Jintu Fan, Qing Chen, Bing Li, Lin Ye, and Dahua Shou. 2021. Personal thermal management by thermally conductive composites: A review. *Composites Communications* 23 (2021), 100595.
[104] Min Zhou. 2018. Towards a poetics of immersion in lyric translation: Aesthetic illusion and the translator as immersive reader in English translations of classical Chinese ci poetry. *Target* 30, 3 (2018), 383–407.
[105] Kening Zhu, Simon Perrault, Taizhou Chen, Shaoyu Cai, and Roshan Lalintha Peiris. 2019. A sense of ice and fire: Exploring thermal feedback with multiple thermoelectric-cooling elements on a smart ring. *International Journal of Human-Computer Studies* 130 (2019), 234–247.
[106] John Zimmerman, Erik Stolterman, and Jodi Forlizzi. 2010. An analysis and critique of Research through Design: towards a formalization of a research approach. In *proceedings of the 8th ACM conference on designing interactive systems.* ACM, Aarhus, 310–319.

A AUXILIARY MATERIALS

https://osf.io/egvtf/

This link points to two files stored on the OSF. The Ci-analysis.xlsx contains 154 Cí poems selected for the corpus. The Ci-extracts.xlsx contains 70 extracts selected from this 154 with full Chinese and English translations to serve as demonstrating examples.