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Aşut, Serdar; Erdem, Arzu

DOI
10.47818/DRArch.2024.v5si152

Publication date
2024

Document Version
Final published version

Published in
Journal of Design for Resilience in Architecture and Planning

JOURNAL OF DESIGN FOR RESILIENCE
IN ARCHITECTURE & PLANNING

Research Article
Online: www.drarch.org
Volume 5, Special Issue, (90-100), 2024
DOI: 10.47818/DRArch.2024.v5si152

A theoretical framework on embodiment in digital design

Serdar Aşut*
Arzu Erdem**

Abstract

This article presents a theoretical discussion on the need for developing digital design environments that can strengthen our relations with the tangible, tacit, and implicit dimensions of design cognition. It synthesizes relevant concepts and theories in the field of phenomenology, addressing creative design thinking. It suggests that designer's tacit ways of knowing can be accommodated in digital design practices by developing tools that allow intuitive and embodied interactions. To this end, it points out specific concepts, methods, and theories within Human-Computer Interaction (HCI) research, arguing that they can enable the development of better digital design tools that can cope with complex human perceptual mechanisms, including touch, as an extension of both body and mind, and that can encompass the implicit areas inherent in design knowledge. Therefore, concerning the creative design disciplines, it highlights the importance of closely following the findings of research within HCI that are relevant to design knowledge and its implementation.

Keywords: design thinking, design methods, digital design tools, computer-aided design, human-computer interaction

1. Introduction

While pioneering studies in artificial intelligence (AI) were gaining momentum, Dreyfus argued that computer systems should have a body to be considered intelligent (Dreyfus, 1967). According to him, studies in the field of AI proceeded with two basic assumptions. The first was an epistemological assumption that all intelligent behavior can be simulated by a detached, disembodied device that is an objective observer. The other was an ontological assumption that everything necessary for intelligence is a determinate set of independent elements. In contrast, Dreyfus argued that the kinds of information processing that cannot be formalized are only possible for embodied beings. The body referred to here is closely related to the phenomenology of embodiment discussed by Merleau-Ponty (Merleau-Ponty, 1962) and is based on Heidegger's definition of being (Heidegger, 1977).

In contrast to rational and empiricist views of human existence, Merleau-Ponty sees the body as the "soil" of human existence and recognizes it as the primary site of experience and expression (Poulsen & Thøgersen, 2011). Mallgrave, who proposes a phenomenological model for architectural research, notes that throughout the twentieth century, the dominant interest of philosophy has focused almost exclusively on the rational aspects of our existence. In contrast, today, we realize that the body also shapes our thinking (Mallgrave, 2015).

The concept of embodiment also offers a valuable perspective on our relationship with computing systems. In creative disciplines such as architecture and design, this perspective can offer the opportunity to discuss the possibilities of human-specific existence in the context of computational design, digital design environments, and AI-based applications. This perspective is essential in supporting the human-centered development of technological tools and methods. This article focuses on the human-centered development of information technologies in the context of creative design practices that deal with the production of three-dimensional and material objects such as architecture, environment, and product design. In this direction, based on historical

*(Corresponding author), Dr., Delft University of Technology, s.asut@tudelft.nl
** Prof. Dr., Istinye University, Türkiye, arzu.erdem@istinye.edu.tr
Article history: Received 07 October 2024, Accepted 20 December 2024, Published 31 December 2024

references, it tries to put forward a conceptual framework based on concepts and approaches in the Human-Computer Interaction (HCI) field.

Discussing that ubiquitous computing will emerge as the dominant form of computer access in the future, Weiser argued that the most profound technologies are those that disappear and weave themselves into the fabric of everyday life until they are indistinguishable from it (Weiser, 1991). This argument refers to the need for information processing and communication systems to seamlessly integrate into everyday environments without being perceived as detached elements. From this perspective, human interaction and communication with these systems should be equally integrated, fluid, and natural. Can humans communicate with computer systems through natural modes of communication, just as they do with each other? This question, which HCI pursues to answer, points to a valid and essential area of research in computational and digital design. Within the scope of this article, the possibilities for developing digital design tools that are relevant to contemporary HCI paradigms; and can integrate and weave themselves into the natural fabric of the act of design while enabling natural forms of communication are discussed.

Designing is an act that requires the acquisition of inherent knowledge and competence regarding the implementation of various skills and tools. It is performed at the intersection of different disciplines. However, this article focuses on the methods and tools particularly used in the early stages of the design process. Hence, design refers to creative actions primarily based on tacit knowledge and carried out intuitively. For this reason, the designer needs toolkits that can encompass tacit ways of knowing and enable them to maintain their intuitive behaviors.

In digital and computational design fields, expert and AI-based applications developed for use in different phases of design processes are becoming increasingly common. However, studies that aim to cover the tacit domains of design knowledge and consider the embodiment approach are quite rare. This situation may even cause concerns and criticisms regarding using these systems in the design process. On the other hand, HCI studies carried out within the scope of computer sciences are leading the way to approaches and applications that can enable the concepts of tacit knowledge and human intuition to be reconsidered in the context of design.

This position paper presents a theoretical discussion in line with these concepts, as well as the background of current work in the field of HCI and critical concepts in this field. It presents a theoretical framework by discussing existing theories and concepts, synthesizing the existing literature and discourses, and refining a conceptual model relevant to the creative design fields (Chapter 2). It starts with a broad discussion on the relationship between tool use and design cognition, structuring a line of thought through arguments in cognitive theories and phenomenology. Then, it refines this line within digital design media, discussing why digital design tools must be developed through an understanding of embodiment (Chapter 3). Finally, it presents the relevant theories, concepts, and methods within HCI research and links them to design cognition to illustrate how digital design tools can address embodiment, allowing intuitive interactions. While doing so, it visits the pioneering historical examples that support these arguments. In this way, we aim to contribute to developing more effective digital design tools that can encompass non-formalizable ways of knowing in the design process, are integrated into the fabric of the design practice, and allow the designer to interact naturally and seamlessly.

2. Tacit Knowledge and Embodiment in the Context of Creative Design

The motivation for this article is to explore the apparent effects of tool use in design cognition within digital media. Dahlbom and Janlert state that just as you cannot do very much carpentry with your bare hands, there is not much thinking you can do with your bare brain (Dennett, 2000). One uses tools to perform physical and mental activities. Whether mental or physical, all activities require a cognitive relation with the tool. The validity of these relations is based on two fundamental theses: first, the tool embodies specific knowledge that not only influences the user's way of knowing but also is influenced by the user's knowledge. Secondly, there are conceptual tools as well as physical ones. Baber illustrates the first thesis by giving the example of the cognitive transformation that takes place when using a shoe sole instead of a hammer to drive a nail (Baber, 2003). Here, the hammer possesses purposeful knowledge. Once the user internalizes this knowledge, it may be adapted to another instrument, in this case, the shoe sole. The second thesis refers to what Vygotsky calls the tools of the mind. The tools of the mind consist of symbolic cultural artifacts such as signs, symbols, texts, formulae, maps, diagrams, and language, and they influence how we think (Vygotsky, 1965).

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Designing involves performing both physical and mental activities. It requires various forms of engagement with both material and immaterial artifacts. It is fully engaged with tool use, both physical and psychological, and the distinction between the two is often unclear. Hence, design media is a better phrase for addressing the diversity and complexity of a designer's tool set. Design media is the environment of the act of design, which is subject to design thinking and execution. It involves the designers themselves and their interactions with various types of tools. Its inherent qualities and economies are encouraged to shape both process and products in a condition of craft (McCullough, 1998); therefore, it is an actuator.

Representation tools constitute the most common realm of design media. Unlike vernacular forms of making, modern disciplinary design methods are closely engaged with representation tools. Indeed, the modern understanding of design fairly addresses the production and processing of representation tools, just like Schön defines design as producing the representations of the things to be built. According to him, design is a reflection-in-action with talking backs, which emerges as the spontaneous reciprocal reflections between the maker and representations (Schön, 1984). However, this precious definition does not address the materiality of design artifacts as a potential participant in the reflective conversation.

Representation is a form of abstraction. Design representation is commonly considered visual abstraction, imagery of the things to be built. Therefore, the sense of sight is hegemonic in our relationships with artifacts in design development and evaluation through their representations. Modernist design methods celebrate the eye as a superior sense organ above the others. They emphasize the praise of sight. They constrain our relationships to the visual in an abstract sense. They distinctly separate design and making. Because, in the age of professionalism and expertise, the designer is responsible for producing rhetoric. Moreover, this rhetoric is principally produced by and for the eye because, as Pallasmaa mentions, sight is the only sense that is fast enough to keep pace with the astounding increase of speed in the technological world (Pallasmaa, 1996). Sontag also mentions the modern praise of sight, emphasizing image. She claims that reality has come to seem more like what is shown by the camera, and the people of the industrialized countries seek to have their photographs taken because they feel that they are images and are made real by photographs (Sontag, 1977). Hence, the image becomes the sole reality in the modern world, and believing becomes a consequence of seeing.

Steiner claims that five classical senses fuse into each other in multiple ways and generate a complex perception system that eventually constitutes twelve senses such as the senses of sight, taste, smell, balance, movement, life, touch, ego, thought, speech, hearing, and warmth (Steiner, 1958). He categorizes them as outward and inward senses. The ones directed more towards the outside are adapted to penetrate the outer world. The inward senses let us perceive ourselves in the things and the effect of things upon us (Steiner, 1981). In this regard, the sense of sight is outward, whereas the sense of touch is inward.

Also, Gibson defines senses as aggressively seeking mechanisms rather than passive receivers (Gibson, 1983) and considers the perceptual system a continuously operating actor. This is strongly related to Merleau-Ponty's definition of embodied perception, which is not a passive receptor activity but an active involvement of the whole body (Merleau-Ponty, 1962). Neglecting this complex system of perception of the involved body and letting the sight be hegemonic over the other senses will disable most of the capabilities of the individual and constrain his/her existence to a witness who has nothing but eyes to perceive; in Pallasmaa's terms, a bodiless observer (Pallasmaa, 1996).

Within the knowledge acquired by perception, Diderot claimed that the eye is the most superficial, the ear is the haughtiest, the smell is the most voluptuous, the taste is the most superstitious and inconstant, and touch is the most profound and philosophical (Diderot & Jourdain, 2010). What is profound about touch is that it is not only a way of receiving but also a way of transmitting. Moreover, Pallasmaa claims that all the senses, including vision, are extensions of the sense of touch, the senses are specializations of the skin, and all sensory experiences are related to tactility (Pallasmaa, 1996). Tactility enables mutual engagement with things. It allows the hybrid assemblage of brains, bodies, and things, which Malafouris defines as how we think (Malafouris, 2013). While the primacy for sight is witnessing, for touch, it is making.

Moreover, our relationships with the material world are not always based on explicit knowledge. Polanyi claims that we can know more than we can tell to refer to the realm of knowledge that is not possible to express by verbal means (Polanyi, 2009). Many of such engagements are rooted in tacit knowledge. Also, the tacit knowledge that many physical situations afford plays an important role in expert behavior (Klemmer et al., 2006). Craft, for example, is a good example of a field where such ways of knowing play an active role. Craftsmanship refers to workmanship using any technique or apparatus in which the quality of the result is not predetermined but depends on the judgment, dexterity, and care that the maker exercises as he works (Pye, 1978). Pye claims that the quality of the result is continually at risk during the making process, so he calls it the workmanship of risk (Pye, 1978). Similarly, Dutta's definition of felicitous error refers to a variation from the programmed and indeterminacies in physical processes and is essential to craft (Dutta, 2007). Both felicitous error and workmanship of risk are rooted in the tacit and inarticulable dimensions of craft skills and are not to be afraid of. Sennet addresses this by claiming that the craftsman's desire for quality poses a motivational danger: the obsession with getting things perfectly fitting may deform the work itself (Sennett, 2009).

Both the practice of design and the fabrication of a design object are directly related to craft. Likewise, a significant part of design knowledge is tacit. According to Cross, what designers know about their own problem-solving processes remains largely tacit knowledge, i.e., they know it in the same way that a skilled person knows how to perform that skill (Cross, 1982). According to Schön, it comes from our actions (Schön, 1983); that is, we know it by acting and perceiving.

We need to consider design as a practice that involves the complex mechanisms of perception and enables various forms of bodily and cognitive engagement between material and immaterial entities. Therefore, we need to develop design media that can perform as actuators in collaboration with the designer. In other words, we need diverse tools, which are the aids of imagination and instruments of thinking tied to the body (Latour & Yaneva, 2017). Thus, they will perform as the extensions of one's bodily range and bodily syn-thesis, as defined by Merleau-Ponty (Merleau-Ponty, 1962).

3. Digital Design Media as an Extension of the Body

There are two crucial notions towards developing digital design media as an extension of the body: the theory of affordances and the synchronization of action and perception. The theory of affordances was initially introduced by psychologist Gibson to address the possibilities of actions that are formed by the relationship between an agent and its environment (Gibson, 1977). Norman introduces this notion into design to address the relationship between a physical object and a person (or, for that matter, any interacting agent, whether animal or human, or even machines and robots). He claims that affordance is a relationship between the properties of an object and the capabilities of the agent that determine just how the object could possibly be used (Norman, 1990). Related to digital design media, the term can relate both to software and input systems. This article focuses on the latter. Common input devices are not capable of performing affordance. As discussed by Sharlin et al., the lack of affordance of the most common computer interaction

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techniques causes uncertainties about the functionalities of input devices (Sharlin et al., 2004). Common interaction methods and devices have a very low level of affordance and can negatively affect cognition, especially in creative practices like design, where the outcome is a three-dimensional tangible object largely identified through its material qualities.

Sutphen et al. seek interface affordances as well as the synchronization of the perception space and the action space for better interactions. They claim that the spatial and temporal natural synchronization of our perception space and our action space enables us to perform complex tasks (Sutphen et al., 2000). The synchronization enables direct and immediate reflections between the maker and the object. Hence, making becomes a dialogue between the object and the maker. The synchronization mentioned here refers to the situation in which the transfer of the input to the system and its perception by the user happens at the same time and place. Sketching in design is a good example of this synchronization. While sketching, the designer visualizes what he/she imagines in its simplest form and in the fastest way and gets the chance to perceive his/her imagination through the same visual instantly. Synchronization enables the practice of thinking in direct, uninterrupted, and instantaneous action between the object and its maker.

The actuator design media must afford the user and synchronize the actions and perceptions. To this end, we need to develop multimodal interaction systems. Multi-modality refers to interaction with the virtual and physical environment through natural modes of communication such as speech, body gestures, handwriting, graphics, or gaze (Bourguet, 2003). Therefore, they incorporate the human sensory systems. In this regard, the interface becomes a natural and organic layer. Actually, in its ultimate sense, this layer entirely ceases to exist.

In order to develop digital design environments that can cope with complex human perceptual mechanisms, including touch, as an extension of both body and mind and that can encompass the implicit areas inherent in design knowledge, it is necessary to closely follow the findings of research within computer science that are relevant to design knowledge and its implementation. In this way, it may be possible to develop strategies that do not weaken our relations with the tangible, tacit, and implicit but strengthen them with the help of adopted technologies. Potential methods enabling intuitive behaviors and hybrid environments that designers seek are being developed within the scope of computer science.

We can now design HCI capabilities where the computer anticipates, predicts, and augments the performance of the user and where the human supports, aids, and enhances the learning and performance of the computer (Grigsby, 2018). Augmented cognition, a form of human-technology interaction where a tight coupling between a user and a computer is achieved via physiological and neurophysiological sensing of the user's cognitive state (Stanney et al., 2009), seeks to advance this human-machine symbiosis through both machine understanding of the human (such as physical state sensing, cognitive state sensing, psychophysiology, emotion detection, and intent projection) and human understanding of the machine (such as explainable AI, shared situation awareness, trust enhancement, and advanced UX) (Grigsby, 2018).

Such environments can foster Hybrid Intelligence (HI), which was introduced by (Dellermann et al., 2019) as the most likely paradigm for the division of labor between humans and machines, aiming at using the complementary strengths of human intelligence and AI, so that they can perform better than each of the two could separately. (Liu & Fu, 2024) emphasize HI's potential in promoting the sustainable development of human society, as it stands out to become the pivotal force driving purposeful and planned sustainable creative behavior in the AI era. Addressing these discussions in the context of design knowledge will pave the way for developing better design tools. The following section presents fundamental concepts and discussions related to these technologies.

4. Possibilities for Intuitive Interactions

The inclusion of various human senses in our interaction with the digital environment is becoming more possible, in line with the developments in HCI technologies. Modern HCI systems consider three modes within this evolution: Command-Line Interfaces (CLI), Graphical User Interfaces (GUI), and Natural User Interfaces (NUI).

CLI refers to the mode of interaction where the user inputs commands to the system through consecutive lines of text. This mode of interaction distinctly separates the perception space and the action space. It requires the use of symbolic systems; hence, cognitively advanced abstraction is essential.

GUI allows the user to interact through graphics on a screen. Interaction is achieved through Windows / Icons / Menus / Pointer (WIMP) interfaces. Yet, many natural human abilities are blocked by the common Keyboard / Mouse / Monitor interface and the WIMP interaction (Sharlin et al., 2001). Also, as 3D object manipulation and movement require much more than a 2 degrees of freedom (DOF) interface, a WIMP method of object interaction tends to interfere with fluidity (Gauldie et al., 2004). In such interactions, the pointer is controlled using generic devices such as the mouse or the fingers on touch screens. These devices do not perform affordance as they do not naturally guide users toward their functional characteristics. They are not functionalized by their forms but by the software used. The use of fingers may have both pros and cons in terms of enhancing the interaction. However, in either way, GUI-based HCI displays all information as "painted-bits" on rectangular screens in the foreground, thus restricting itself to very limited communication channels; and they fall short of embracing the richness of human senses and skills people have developed through a lifetime of interaction with the physical world (Ishii & Ullmer, 1997).

The still hypothetical concept of NUI aims at providing more intuitive interaction modes. NUI needs to be multimodal, invisible, and intuitive. Affordance is key to intuition. So, a novice user can intuitively start using the system and experience a steep learning curve. NUI is relevant to most everyday interactions with the material world through tactile engagements. Indeed, the most seamless interaction with computer systems could emerge by changing the world into an interface, in Ishii and Ullmer's words (Ishii & Ullmer, 1997). And by moving the interface out of the screen, we move it closer to the human world (Svanæs, 2009).

One can find potentials for enhanced, bodily, and intuitive interactions with digital design media through certain key concepts of the so-called third-wave HCI, named the phenomenological matrix by Harrison et al. The third-wave treats interaction not as a form of information processing but as a form of meaning making in which the artifact and its context at all levels are mutually defining and subject to multiple interpretations (Harrison et al., 2007).

Schmidt defines the concept of implicit HCI (iHCI) as an action performed by the user that is not primarily aimed to interact with a computerized system but which such a system understands as input (Schmidt, 2000). The implicit dimension of HCI is rooted in certain concepts within the discipline of Human-Centered Computing, such as Ubiquitous Computing (ubicomp, also called Pervasive Computing), Calm Technology, Context Awareness, Intelligent Environments (IE), and Ambient Intelligence (AmI). Each concept is strongly related to the other while having minor differences.

Satyanarayanan characterizes a ubicomp environment as one saturated with computing and communication capability, yet so gracefully integrated with users that it becomes a technology that disappears (Satyanarayanan, 2001). Calm technology refers to the computer systems that engage both the center and the periphery of our attention, while the periphery stands for what we are attuned to without attending to explicitly (Weiser & Brown, 1997). Context-aware computing is the ability of a mobile user's applications to discover and react to changes in the environment they are situated in (Schilit & Theimer, 1994). Augusto et al. define IE as environments in which the actions of numerous networked controllers are orchestrated by self-programming pre-emptive processes

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in such a way as to create an interactive holistic functionality that enhances occupants' experiences (Augusto et al., 2013). AmI refers to electronic environments that are sensitive and responsive to the presence of people (Aarts & Encarnação, 2006).

As a result, the hybrid design media of intuitive interactions is a matter of environment in which the computer system disappears. It is programmed and functionalized in a way that is aware of the user and the particularities of the context of use. This notion addresses Norman's definition of soft technology (Norman, 2014). He argues that soft technology refers to compliant, yielding systems that informate and provide a richer set of information and options than would otherwise be available. He also states that these systems acknowledge the initiative and flexibility of the person, whereas hard technology refers to systems that prioritize technology with inflexible, hard, rigid requirements for the human.

Developing our interactions with computer systems in line with these approaches will enable easier end-user integration while obtaining outputs easily. Particularly in design domains, such systems will allow more direct, seamless, and organic interaction between the designers and the objects while enabling humans to use their complex perceptual mechanisms and intuitive skills. Furthermore, they will enable designers to maintain the practice of fluid thinking, such as sketching, while utilizing the possibilities of digital technology. What is needed for this is to consider the knowledge, concepts, and methods in HCI and related fields when developing design tools.

Looking at the historical development of digital design media, one can observe that explorations that could relate to the concepts of embodiment, tacit knowledge, and intuitive interaction discussed in this article can be seen even in the early works of this field. For example, in the 1960s, Sutherland mentioned that most interaction between man and computers has been slowed down by the need to reduce all communication to written statements that can be typed (Sutherland, 1964). He developed a system called Sketchpad, which was in favor of line drawings instead of typed statements in the early 1960s. It was the pioneering demonstration of direct user input into digital design media. Therefore, it is often coined as the first GUI or HCI application for CAD. Sutherland proposed a tangible device: a light pen integrated with a control box containing command buttons like draw, move, or rotate. The device allowed the user to use his/her hands in real 3D to perform certain functions. It enabled spatial interaction through a handheld device, while today's most common input devices, like the mouse or touchpad, can operate only on 2D surfaces.

Explorations towards more enhanced interactions date back to the 1970s. The Architecture Machine Group of Nicholas Negroponte was one of the pioneers who worked on outstanding projects such as the Seek (Negroponte, 1970). It demonstrated a possible direct relationship between the model world and the real world. It included 500 metal-plated cubes of 5 cm dimension and curious gerbils inside an enclosed space. The gerbils were constantly moving the cubes. These movements were being recorded and repeated by a robot arm. Negroponte defines the output as a constantly changing architecture that reflects how little animals used the place.

Aish claimed that it is often difficult for the user of conventional graphic computer-aided architectural design (CAAD) systems to conceptualize the building being designed by only inspecting and manipulating drawings displayed on the screen. He proposed a 3D input method for CAAD systems to complement the graphical channel of man-machine communication by enabling much of the 3D information to be communicated by the designer directly to the system (Aish, 1979). Such a system could eliminate the need to learn operating commands for interaction (Aish & Noakes, 1984). It was an early significant demonstration of the applicability of hybrid design media, which naturally complements the human intuitive skills and the capabilities of the computer.

As seen in these early works, the idea of creating embodied, three-dimensional, intuitive, and hybrid interaction possibilities with digital design media has existed since the beginning of their development. Current technologies and approaches in the field of HCI can make it more possible to realize such interactions in more seamless ways.

Several existing studies in this field can help understand how hybrid interaction methods might evolve and how they can be effectively utilized in design fields. They are mostly developed for general design applications (Follmer & Ishii, 2012; Huang & Eisenberg, 2012; Vuletic et al., 2021), while some of them address specific design disciplines such as architecture (Johns, 2013; Mitterberger et al., 2020; Yoshida et al., 2015) fashion design (Iarussi et al., 2015), urban design (Han et al., 2023), landscape design (Ishii et al., 2004), or arts (Shilkrot et al., 2015; Yao et al., 2024). They are mostly used for digital modelling and visualization (De Araújo et al., 2013; Momenaei et al., 2021), while the ones that are used for tangible applications such as fabrication and physical object manipulation (Burden et al., 2022; Weichel et al., 2015) have been increasing in the last decades too. Most applications are developed for designers to use (Devendorf & Ryokai, 2015), while some target end users for participatory or Do-It-Yourself design purposes (Beattie et al., 2015), and others are developed for craftsmen or makers involved in the fabrication process (Frost et al., 2024; Mitterberger et al., 2022; Zoran & Paradiso, 2013).

(Niu et al., 2022) present a review of multimodal natural human-computer interfaces for computer-aided design, categorizing them as eye tracking, gesture recognition, speech recognition, and brain-computer interface-based systems. Also, (Vuletic et al., 2019) present a literature review identifying the characteristics of gesture-based interaction interfaces through visual-based sensors and cameras, and physical wearables. More research is needed to outline how tangible and bodily interaction can advance HCI research in design. For this, it is necessary to consider approaches to developing these technologies that encompass the implicit domains of design knowledge and action and understand the digital environment as an extension of the body and the material environment.

5. Conclusion

At a time when digital technologies and artificial intelligence-based applications are becoming increasingly widespread, it is important to question the possibilities of technology to develop in a human-centered direction. The concept of embodiment can provide a guiding conceptual framework by drawing attention to the relationship of thinking with the body and the physical environment. This framework is even more vital in creative design practices such as architecture, environmental, and product design, where the end product is a material object. Approaches and paradigms in the field of HCI guide the development of contemporary design tools to encompass the implicit and intuitive design domains.

The creative design process is significantly influenced by the environment in which it takes place. This process involves the designer's complex sensory and perception system, including their body. As a result, the designer must be able to interact with design tools both physically and mentally, a principle that holds true in digital design. Therefore, there is a need for explorations that can enable multimodal communication and the use of design tools as an extension of both the mind and the body. The development of technology in this direction, utilizing the concepts, approaches, and techniques in the field of HCI, is critical for the future of design as an embodied creative practice.

The digital design environment can be reconsidered so that the designer can interact with his/her tools multimodally, with a high level of affordances and synchronization of action and perception. The sense of touch has a special place in this interaction and requires the use of a three-dimensional natural environment. Studies in the field of HCI, especially the developments within the so-called third-wave paradigm, can be instructive in this direction. Therefore, concepts such as iHCI, distributed computing, serene computing, context-aware systems, intelligent environments, and ambient intelligence should be emphasized in the context of design tools. These concepts have been of interest since the early days of computer-aided design research, and a body of work can guide us in this regard. Evaluating recent innovations in HCI in the context of design knowledge will support the human-centered development of design tools, making it possible to use them as extensions of both the mind and the body.

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Resume

Dr. Serdar Aşut is an educator and researcher at the Faculty of Architecture and the Built Environment of TU Delft. He is an architect and holds a PhD in Architectural Design Computing. His works explore topics at the intersection of digital technologies and the built environment, including computational methods, creative robotics, digital fabrication, and architecture and design education.

Prof. Dr. Arzu Erdem currently works at Istinye University and serves as the Dean of the Faculty of Fine Arts, Design and Architecture. Her research interests include design education, computational design thinking and interdisciplinary strategies of design practice and education. She has designed several architectural projects and contributed to architectural design competitions. She is currently on the Board of Directors of Rubicon Foundation (The Netherlands) and the Board of Directors of Kale Ceramic INC, SEV Foundation and ITU Development Foundation.