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BERRE SU DEMIR, Koç University, Istanbul, Turkey

AYKUT COŞKUN, Koç University, Istanbul, Turkey

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Rethinking Representation in Design: Towards Constructing Parameters for Representation Tools in More-than-Human Design

Berre Su Demir
Koç University
Koc University Arçelik Research Center for Creative Industries
İstanbul, Turkiye
byanlic16@ku.edu.tr

Aykut Coşkun
Koç University
Koç University Arçelik Research Center for Creative Industries
İstanbul, Turkiye
aykutcoskun@ku.edu.tr

Abstract

Understanding and representing user perspectives is essential for designing user-centered products, services, and systems. The emergence of More-than-Human Design (MTHD) expands the scope of "user" to include nonhumans, challenging the usefulness of existing user representation tools for MTHD and thus motivating design researchers to devise new tools or adapt existing ones to MTHD contexts. This paper reviews 40 design research studies to investigate representation tools in MTHD, analyzing represented nonhumans, modalities, and contexts. The paper contributes to the literature by identifying six parameters of user representation tools in MTHD: transferability, depth of representation, transcendentality, multi-perspective integration, scalability and flexibility, and resource investment. We discuss the implications for defining and conceptualizing user representations in MTHD and designing new tools by balancing didactic and interpretative representation techniques.

CCS Concepts

• **Human-centered computing** → Human computer interaction (HCI); HCI theory, concepts and models.

Keywords

more-than-human, user representation, user perspective, nonhuman representation

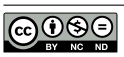
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1 Introduction

Design is a service-oriented practice that relies on understanding users, their needs, current experiences, and future aspirations to create meaningful and responsive solutions. This understanding is crucial for designing usable products, services, and systems that enhance the quality of the user experience. Acknowledging the significance of needs elicitation for Human-Centered Design (HCD), designers and design researchers utilize various techniques to gather user insights, such as interviews, focus groups, and diaries. Then, these insights are transferred into shareable and actionable formats by using tools such as personas, empathy maps, and journey maps. These tools, which are used to represent user needs (i.e., user representations), have been very instrumental in developing user-friendly designs despite the recent criticisms of their usefulness [8, 49].

The recent introduction of More-than-Human (MTH) perspectives to the field of design has ignited a new discussion surrounding user representations. Within the More-than-Human Design (MTHD) discourse, scholars have highlighted the limitations of human-centered approaches in addressing complex environmental and ecosystem-level challenges, leading to the development of alternative tools that decenter human users and integrate nonhuman perspectives into the design process [4, 21, 85]. MTHD emphasizes that humans and nonhumans exist within an interconnected network, and both experience the consequences of environmental challenges [20, 31]. For example, terrestrial biodiversity is threatened by land use changes such as farmland expansion [48], extreme heat and droughts negatively impacting animal health [44]. The integration of MTH and post-humanistic values into design research and practice [2, 13, 53] has redefined the concept of the "user", extending it beyond the human-centric perspective to encompass both humans and nonhumans [12, 53], including but not limited to animals [4, 57, 86], things [9, 51, 61], and ecological systems [5, 47, 56]. With this expansion, understanding and representing the perspectives of nonhumans has emerged as a crucial design research activity.

Using existing representation tools commonly used to represent humans is challenging for incorporating nonhuman perspectives into the design process. While tools like persona, empathy map, or user journey map may be useful in HCD, they often fall short because they are primarily tailored to human cognition, behaviors, and needs, failing to account for the distinct experiences, agency, and ecological interconnectedness of nonhuman entities. This limitation becomes particularly problematic in MTHD, where stakeholders are understood as entangled entities [20, 31], since neglecting relational aspects risks narrowing the focus to a single type of user (whether human or nonhuman) in the design process. Furthermore, these tools are designed to synthesize data gathered from humans; therefore, they lack specific aspects essential for representing nonhuman stakeholders [89]. For example, animals



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and plants often follow biological rhythms such as migration, hibernation, and flowering cycles, which are shaped by environmental cues like light and temperature and are essential for survival and reproduction [87]. In contrast, humans have adapted to mitigate seasonal effects through technology such as heating/cooling systems, lighting devices, refrigerators, etc.

In searching for ways to represent nonhumans in the design process, some design researchers attempted to adapt human-centered representation tools to incorporate nonhuman perspectives. These include Nonhuman Persona [79], Animal Persona [22, 34] and Objects Persona [8], which were based on the original concept of persona. Other examples include Experience Map [90] and Scenarios Envisioning [66], which are adapted from user journey maps. Apart from these adapted tools, several representation tools are specifically designed to represent nonhuman stakeholders in design. Examples include Dirty Nails, which uses sonification to represent minerals in soil [58], and Stromatolive which uses visuals, sound, and tactile interaction to represent "stromatolite's growth pattern in different tidal zones" [82].

What is common in all these tools, whether they are new or adapted from an existing tool, is that nonhumans do not directly represent themselves; they need a "voice", which often belongs to a human. This situation raises some questions. For instance, which information is essential for representing a nonhuman? How should this information be collected and communicated? During the communication, who should be the 'voice' of the nonhuman? These questions highlight the distinct needs of designers working in MTHD, reflecting the unique considerations involved in engaging with nonhuman perspectives, and further emphasizing the challenges they might face.

Selecting appropriate tools or devising new tools for representing nonhumans in MTHD is not a trivial task. The tools are scattered across different studies that were conducted in diverse contexts such as smart mobility [9], conversational agents [61], urban farming [58], etc. Plus, the literature lacks a comprehensive study analyzing the representation tools utilized in these studies in terms of the nonhumans represented through these tools, the entities that represent nonhumans, the way nonhumans are involved in these studies (e.g. data collection methods, representation mediums), the contexts of these representations (e.g. where, and why), the impact of these representations on the design process, participants, and nonhumans, and finally their strengths and limitations. Moreover, MTHD researchers and practitioners lack guidance on how to select tools for representing users and implement and assess the quality of the representations.

To address these gaps, we analyzed 40 MTHD papers involving nonhuman user representations through an exploratory literature review. We contribute to the literature by 1) providing an account of diverse representation tools currently utilized in MTHD (i.e. the types of nonhumans they represent, the modalities they employ, and the contexts and settings of their use), and 2) constructing six parameters for MTHD representations, which could be used to classify representation tools in MTHD and reflect on their qualities. Furthermore, we discuss the implications of the results for defining and conceptualizing user representations in the MTHD and designing new representation tools by considering the trade-offs between didactic and interpretative techniques.

In the remainder of this paper, we first explain the scope of representation in HCD and MTHD, providing tools that represent users in HCD and previous studies that give a catalog of representation tools used in MTHD. We then outline our identification and screening process for the MTHD studies as well as the methods used for analysis. Following this, we present our results, providing an overview of the status of representation in MTHD, an account of nonhuman users represented, the modalities employed by the representation tools, the methods of data collection, the types of data gathered for representation, and the context of representation. Following this, we describe the six parameters for representations in MTHD (i.e., transferability, depth of representation, transcendentality, multi-perspective integration, scalability and flexibility, and resource investment) and present examples of tools from the reviewed studies to better contextualize each parameter. Finally, we discuss the implications of our study for representing nonhumans in the MTHD.

2 Related WORK

2.1 Representing users in HCD

User representation in design refers to various ways user perspectives, needs, and experiences are portrayed and incorporated into the design process [38]. These representations help designers build empathy with the users [39], make the design process less complex by focusing the design team on a specific user group, guide the ideation process [14] and create a common ground among team members [27]. There have been valuable works that showcase the diverse user representation techniques used in design, such as the work of Hanington and Martin [29]. The reader should note that our purpose in this paper is not to provide an extensive list of representation techniques in HCD but rather to discuss some example tools that are often adapted for MTHD contexts.

Personas are widely used in HCD to represent fictional yet research-based user profiles, capturing user goals, needs, and behaviors to make abstract data more tangible for design teams [28, 66, 92]. They foster empathy and facilitate communication within teams by representing a specific user type at a specific moment [66]. However, designers may feel disconnected from them, often relying on intuition rather than persona-driven insights due to time or budget constraints. They also risk marginalizing minority users by reflecting the needs of the majority and becoming overly generic or stereotypical, losing the nuances of real user experiences [28, 93].

Empathy map, similarly, focuses on what a user "says", "thinks", "does", and "feels" during interactions with a product or service. It helps design teams uncover hidden needs, improve team communication, and identify design opportunities. However, they may oversimplify complex behaviors, lack broader context, miss the dynamic nature that's involved in user emotions and thoughts, and may become outdated if not regularly revised [94, 95].

Journey map introduce a temporal dimension to user representation, illustrating how users interact with a product, service, or system over time [36]. It helps visualize complex processes, identify key tasks and opportunities, engage multiple stakeholders, and support planning and design decisions. However, creating a separate map for each stakeholder can be resource-intensive [17]. Furthermore, it may attribute equal importance to all parts of a

journey, which may not necessarily reflect real life, e.g., the actions, thoughts, and emotions of a user when uninstalling an app may be more important from a design perspective than the ones in onboarding phase and vice versa.

Experience maps and service blueprints offer broader system-level insights. Service blueprints focus on user interactions with an organization, including the backstage service processes. They provide a clear, structured view of service processes and are easy to use in co-creation with minimal research. Yet, they often miss emotional or contextual nuances. Experience maps highlight how an organization fits into a person's life, emphasizing lived experiences in a wider context. While they foster empathy and uncover broader insights, their abstract nature can make them challenging for some stakeholders to engage with and overly detailed maps may lead to over-analysis or mapping overload [41, 96].

Stakeholder mapping identifies and analyzes individuals, groups, or entities involved in a system, highlighting their roles, influence, and relationships. Unlike personas or journey maps, it emphasizes power dynamics and interconnected stakeholders. While stakeholder map offers mostly the same benefits as previous representation tools, it can be challenging to use in complex settings involving many stakeholders, and it requires carefully assessing each stakeholder's influence to avoid disrupting power dynamics [7].

Ecosystem mapping, similarly, is used to understand the broader context in which a product or service operates. It illustrates the relationships among users, stakeholders, systems, platforms, and environments [97, 98]. It encourages systems thinking, supports team alignment, and reveals gaps or opportunities across touchpoints. However, it often lacks sequence or emotional nuance and can be time-consuming to create. [41].

User representation in design occurs not only through representation tools but also via direct user involvement, as seen in Participatory Design (PD). PD aims to equalize power relations by enabling marginalized voices and supporting context-sensitive solutions [75]. It has been applied in diverse contexts, from co-designing with seniors [16, 73] to developing social and technical infrastructures [74].

While representation tools offer an efficient way to summarize and communicate user insights, PD directly involves users as co-creators, leveraging their perspectives to produce user-centered outcomes. However, PD poses several conceptual and practical challenges, including configuring participation and balancing involvement, control and benefit distribution, which is often shaped by researchers and funders rather than participants. As [84] notes, PD is frequently researcher-led, with designers retaining authority, which can reinforce power dynamics and limit genuine stakeholder agency. The goal of empowering marginalized users can be undermined when participation is organized primarily to align with researchers' agendas. Additionally, [43] argues that power imbalances, cultural diversity, and logistical constraints can further hinder meaningful collaboration.

We argue that both conveying user perspectives through representations and involving users in the process are valuable approaches, each with its benefits and challenges in MTHD. Within the scope of this paper, we focus on the former approach, i.e., user representations, as there is growing interest in representation tools within the MTHD community. A deeper, critical analysis of these tools can support their more effective use and guide the design of improved ones.

2.2 Representing users in MTHD

Incorporating nonhuman perspectives into the design process requires acknowledging their interconnections with humans and addressing their needs [20, 47]. This presents a challenge, as (human) designers often struggle to empathize with nonhumans due to the tendency to interpret them through human-centric lenses [32], while nonhumans lack the ability to articulate their needs and experiences [33]. Consequently, the effectiveness of existing human-centered tools, such as persona, empathy maps, and journey maps, in representing the perspectives of nonhuman stakeholders is questionable due to their inherent anthropocentric focus. These tools are designed to synthesize human behaviors, emotions, and needs into simplified and actionable formats for designers, relying heavily on verbal, cognitive, or behavioral data. For example, personas generally include user demographics, goals, and pain points derived from interviews or surveys which might be impractical to understand the experiences of nonhuman stakeholders like animals or plants. Similarly, empathy maps, which focus on what a user "says," "thinks," "feels," and "does," rely on observable human interactions and emotional expressions, making it difficult to apply these categories to nonhuman stakeholders. Hence, utilizing tools rooted in HCD practices might be limited in MTHD.

In response to these limitations, several researchers have developed alternative representation tools to better represent nonhuman perspectives. Some existing works have begun to examine these tools and their applications. For instance, Eriksson et.al. [18] map the emergence of MTH perspectives in HCI by identifying key motivations, approaches, and practices, outlining the field's current state, and discussing the role of design in shaping MTH HCI. In their scoping review, they mention some representation tools such as High Water Pants [5] and thingCV [37] as examples of different types of research contributions and discuss representation as a motivating factor in some of the articles in their corpus. However, the review does not specifically address representation tools as design tools; instead, it focuses on how various technologies support the representation of different species in the design process, such as by developing prototypes that provide cognitive and sensory enrichment for elephants [23].

In another study, Tomico et.al. [77] present an emergent repository of "methods-to-be" for nature-entangled design research that is developed and explored through a conference workshop. In this pictorial, the authors showcase unfinished, in-progress methods that are organized into five overlapping design process categories: sensitising, developing relations, generating data, ideating, and evaluation. Among these methods, some aim to represent nonhuman perspectives and relations such as "Mapping relational dynamics" designed to explore and document the connections between species within an ecosystem. It involves creating species profiles and visually mapping their interactions such as cohabitation, shared habitats, or predator-prey relationships.

Honauer [35] analyzes three distinct case studies to explore how nonhumans can be given a co-creative role in the design process.

Although only one of the cases explicitly focuses on representation (the other two lean more toward PD, in our view), the author still offers valuable insights into representation. For example, they note that in representational contexts, humans often rely heavily on input from nonhuman actors, with their role being to interpret and act upon this data. Since control is shared between humans and nonhumans in these representations, the distribution of agency must be handled thoughtfully and responsibly.

Finally, in [89], Yanlıç and Coşkun analyze the methods used in MTHD studies to explore and synthesize the nonhuman perspectives. They categorize these methods into data gathering, reflection, and imagining methods. They discuss the limited number and diversity of representation methods compared to the wide range of available exploration methods, noting that existing representation tools are largely adaptations of the persona.

Although these studies touch on representation tools, their primary aim is not to investigate them in the context of MTHD. They do not examine these tools in detail across dimensions such as purpose, limitations, or advantages. In contrast, our work explicitly centers on representation tools, offering a more detailed analysis of those used in MTHD by searching across a broader database.

As the literature evolves, new studies continue to introduce diverse representation examples for MTHD, with some being newly developed and others adapted from human-centered practices. However, there is no established guideline for assessing their quality, and the rationale behind tool selection and their effectiveness often remains unclear. Additionally, there is limited understanding of how to evaluate them across different contexts, making it challenging to determine their suitability and impact. Furthermore, within the studies utilizing these tools, there are highly valuable reflections, but these insights often remain scattered across individual papers, making it challenging for researchers and practitioners to identify recurring patterns or build upon previous work. This highlights the need for not only deeper, more detailed analysis but also a comparison across cases to build a comprehensive understanding of the tools and their broader implications.

In this paper, we address these gaps by conducting an analysis of 40 papers that utilize representation tools in MTHD contexts. Our research seeks to answer how nonhuman stakeholders are represented in design studies. By examining these papers, we identify the tools used for representing nonhuman perspectives, and their distribution among various nonhumans and modalities, and propose six parameters for selecting, evaluating, or classifying representation tools in MTHD. By doing so, we aim to contribute to developing more effective representation tools and provide recommendations for their mindful application in MTHD.

3 METHODOLOGY

We conducted an exploratory literature review to identify and analyze the papers that utilize user representation tools in MTHD contexts. The sections below explain the procedure of this review. While understanding nonhuman stakeholders and representing them are deeply intertwined processes in MTHD, our review specifically focuses on representation. In many cases, understanding precedes representation (e.g., [19]), and in others, representation becomes a means of understanding (e.g., [40]).

For this study, we focus on how nonhumans are represented (i.e., how their presence, needs, and perspectives are expressed) through different tools. More specifically, we refer to representation in this paper as the ways of synthesizing data related to nonhumans and/or their relations with other stakeholders. Furthermore, with "nonhuman" we refer to many entities including plants, animals, microbes, things (e.g., inanimate objects like a kettle, or AI), inanimate natural (e.g., sea, mountains, rocks, etc.), nature, and ecosystems.

3.1 Keywords and search engines

We initiated our search by conducting title and abstract queries across three databases: ACM Digital Library (ACM DL) and Design Research Society Digital Library (DRS DL) as domain-specific libraries, and Scopus as a general-purpose library. ACM DL and DRS DL include articles from premier venues where much of the recent and prominent MTHD work has been published, including several method papers mentioned in the Related Work. To complement these domain-specific databases, we included Scopus to capture a broader range of articles outside design and HCI venues. We gathered all the articles that meet the following conditions:

- **For ACM DL and DRS DL:**
  - "More-than-human" appeared in the title OR abstract
  - "nonhuman" appeared in the title OR abstract
  - "non-human" appeared in the title OR abstract
- **For Scopus:**
  - "More-than-human" appeared in the title OR abstract AND "design" appeared in the abstract
  - "nonhuman" appeared in the title OR abstract AND "design" appeared in the abstract
  - "non-human" appeared in the title OR abstract AND "design" appeared in the abstract

Since Scopus is a general-purpose database, the additional condition of "design" in the abstract was applied to refine the search. While no lower limit was set for publication year, the upper limit was defined as 2024, the year the study was conducted. While reading the papers, the first author also checked the Related Work section of each paper to gather studies that are related to our search. This yielded a total of 1687 papers (see Figure 1 for the PRISMA chart and detailed numbers).

3.2 Selection criteria

Following this initial collection, we removed the duplicates, and filtered the remaining papers using the following inclusion criteria:

- At least one tool used in the study should represent nonhuman perspectives or relations between nonhumans and other stakeholders, even if this was not the initial intent.
- The paper should be peer-reviewed, either full or a short paper.
- The paper should be written in English.

Additionally, papers were excluded if they met any of the following criteria. After applying these criteria, we ended up with 40 papers (Figure 1).

- Studies that include nonhumans but do not represent nonhuman perspectives or nonhuman-other stakeholder relations

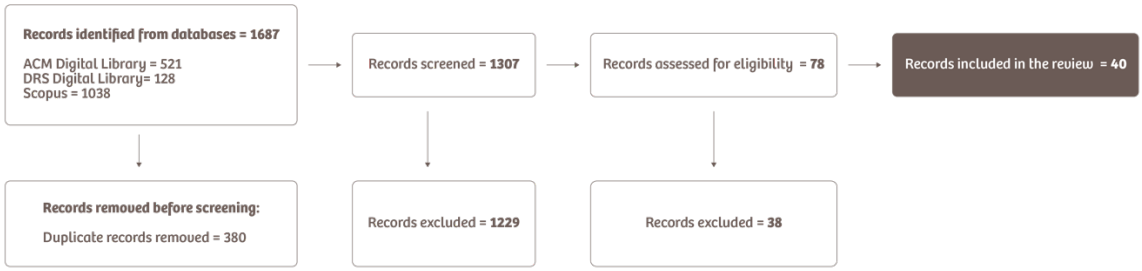


Figure 1: PRISMA chart for the exploratory literature review

(for instance, the Glowing Nature [21] installation used bioluminescent algae to create interactive light effects. The installation did not attempt to represent the algae's perspective or its relations; algae was used as an aesthetic element rather than represented as stakeholders.)

- Representations were not created to transfer information to others. We excluded studies in which representations were used solely for paper-writing or self-reflection purposes, as they do not provide insights into how the representations functioned as tools within a broader design process. For instance, Stead and Coulton [72] use "Defuturing Ontography" figure to better communicate the defuturing potential of human/nonhuman design assemblages to the reader, meaning that is created for paper-writing purposes and we cannot learn about authors' reflections on the use or creation of the figure. Similarly, Lenzi et.al [45] use a self-reflective representation of a breastfeeding pump but the paper lacks engagement with others, making it unsuitable for our analysis of representation tools.

3.3 Analysis

Figure 2 presents our coding process. Accordingly, the first author read all the papers, skimming and scanning each paper to get a sense of their content and level of detail (e.g., whether data collection methods or reflections on tools were clearly presented). To guide the analysis, we developed a set of questions informed by our research aim, i.e., exploring how nonhuman stakeholders are represented in design, the content of the existing papers, and the themes in the literature on user representation in MTHD such as voice (i.e., who creates the representation) [3] and the ways nonhumans are involved in the representation [15]. The first author then read the papers thoroughly, taking notes and identifying relevant passages while responding to these questions:

- **Which nonhumans are represented?**
- **Who represents them?**
  - Who is involved in preparing the representation?
  - What are the different roles of the representatives?
  - What is their level of involvement in preparing the representation?
- **How are the nonhumans involved?**
  - Which medium(s) are used for representation?
  - What data is collected?
  - How is the data collected?
- **In what context does the representation take place?**
  - Where does the representation take place?
  - For what purpose is the representation designed/used?
- **How does the representation impact the design process/output?**
- **How is the representation evaluated by the authors?**
  - What are the positive aspects of the representation?
  - What are the limitations of the representation?

The relevant text from each paper was then pasted into an Excel sheet, indexed by paper numbers. The first author coded this text using the research questions as a reference, identifying elements such as the different modalities employed, and the types of nonhumans represented (see Table 1 for a coding example).

We used the first four questions (corresponding category tags: C1 to C9, C13, and C14 in Table 1) to review the representation tools in MTHD, and the last two questions (corresponding category tags: C10 to C12 and C15 in Table 1) to construct the parameters of nonhuman representations. For the construction of parameters, first author collected all insights that correspond to C10, C11, C12, and C15 in Table 1 and thematically grouped them using their prior experiences with representation tools. Then in biweekly meetings, the first and second authors held discussions to refine the groups. In these meetings, authors discussed the groupings of insights (e.g., whether a particular insight meant different things to two authors or whether they placed the same insight into different groups) based on their prior experiences. They also discussed the definitions of groups, removed redundancies, and introduced new groups where necessary. For instance, in the first-round expertise and resource investment were separate categories, through discussion we decided to merge them.

Through a deeper analysis of the papers in our corpus, drawing on insights gathered from the reviewed studies (i.e., the study authors' reflections on each representation tool and their reported impact on the design process or outcomes) and informed by our prior experiences working with representation tools in MTHD contexts we constructed six parameters of representation tools in MTHD.

Once the parameters were finalized, the first author coded each insight from C10 to C12 and C15 according to the most relevant parameter. Each tool had at least one identifiable insight that aligned with one or more parameters, which allowed us to associate every tool in the corpus with at least one parameter. However, not every paper provided sufficient insight into every parameter. For

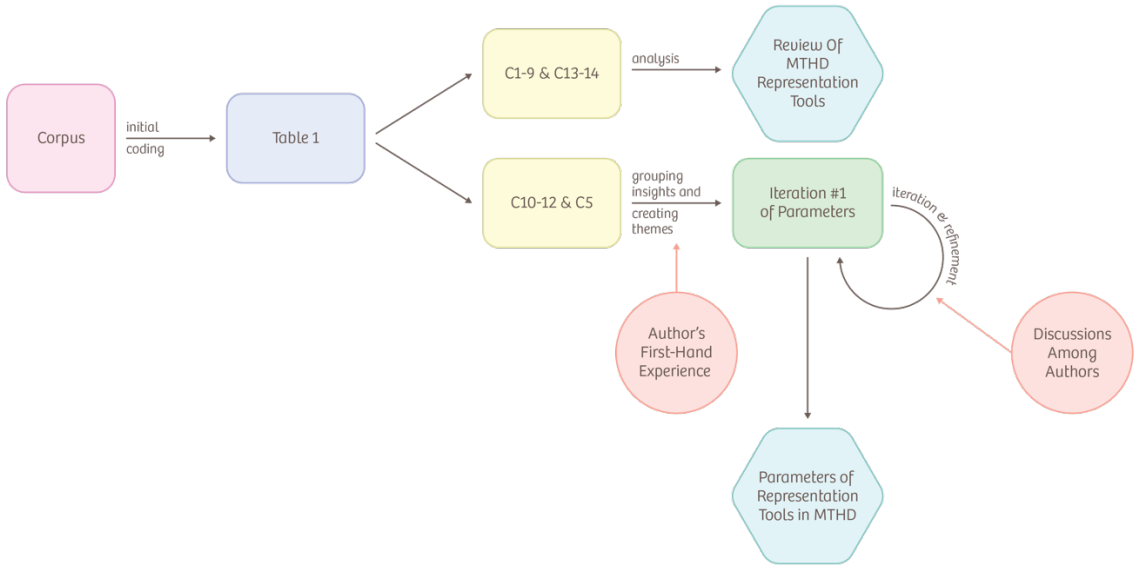


Figure 2: Overall coding process

instance, while Actant Mapping [78] includes reflections related to transferability, it does not include insights on the balance of focus or transcendentality. Thus, we chose not to generate a comprehensive tool-to-parameter matrix. Instead, to clarify and contextualize the parameters, we present example tools that contain direct reflections or insights relevant to each parameter (see Table 2).

4 RESULTS

The first section of results presents an overview of the representation tools according to how they are utilized, the types of nonhumans they represent, the modalities they employ, the contexts and settings of their use. The second section describes and exemplifies the parameters for selecting, evaluating, or classifying representation tools in MTHD. The parameters are intended to support researchers and practitioners in reflecting on which aspects a tool foregrounds, what it may overlook, and how well it aligns with the goals, stakeholders, or settings of a given MTHD project.

4.1 Overview of representation tools in MTHD

We identified a total of 48 tools (41 different tools) across 40 studies[1]. Most methods were unique and used in singular cases, with few exceptions, such as persona, chromatography, thing interview, and phenology wheels. Adoptions of persona were used in 8 cases (3 animal personas, 3 nonhuman personas, 1 object persona, and 1 plant persona), indicating its versatility. Chromatography, thing interview, and phenology wheels were each employed in two studies. In other studies, researchers develop specific methods for specific contexts and nonhumans.

[1]The number of studies, tools, and nonhuman representations is not equal because a single study can discuss multiple tools, and a single tool can represent multiple nonhuman stakeholders.

4.1.1 Which nonhumans are represented? Figure 3 provides an account of some of the nonhumans already represented in MTHD through the years. A range of nonhuman stakeholders were represented in the reviewed studies, including animals (e.g., dogs [34, 42, 70, 80], pigeons [81], seagull [91]), plants (e.g., olive trees [90], moss [71], tobacco [40]), inanimate nature (e.g., tides [59], soil [24, 58, 64], rocks [82]), and things (e.g., kettle [11], chair [78], robots [65]). Some studies also included representations of microbes (e.g., lactic acid bacteria [10]), nature (e.g., [63]), and ecological systems (e.g., [6]). In certain cases, individual tools were designed to engage with more than one type of nonhuman stakeholder. For example, the Drawing & Visual Mapping [63, 91] tool was used to explore perspectives of animals and plants. Similarly, some tools such as Nonhuman Persona [79], Games [55], Photography [42], and Posters & Zines [60] represented multiple nonhumans within a single study, illustrating the complexity of interactions across different stakeholders.

When we examine the catalog of represented nonhumans, we observe three distinct types of indication: first, references to specific individual entities (e.g., crows [82], monstera deliciosa [88]); second, broader references to species or categories (e.g., plants [30]); and third, collective or systemic references (e.g., nature [62, 63], ecosystems [6]).

4.1.2 Who represents them? We identified three approaches used to prepare nonhuman representations. In the first approach, a research group collected data, developed representations, and shared their outputs with each other for reflection (e.g. Dear Nature [19]). Second, researchers and participants (ranging from those with specific interests in nonhumans or sustainability to those without any prior interest) collaborated to collect data and co-created representations (e.g. Paper Chromatography [64]). Third, researchers independently collected data, created representations, and then

Table 1: Example coding

Category Tag	Categories	Example Coding
C1	Representation Method	Tracing Tides
C2	Theoretical Foundations	Cartography
C3	Representation Modality	Visual
C4	Represented Nonhuman(s)	Tides (natural and historical flows) (Inanimate natural)
C5	Representation Purpose	"To create a better understanding and promote engagement with coastal and intertidal places by capturing multiple temporalities." "To combine space and time in a cartographic process with artefacts that brought together heterogeneous data and multiple perspectives."
C6	Data Type	Observations on tides Georeferenced data on high/low tides
C7	Data Collection Methods	Observation, picture and note-taking, talking with people from different disciplines
C8	Representation Team	Interdisciplinary group of researchers and practitioners
C9	Representation Team's Role	Collect data via field work and visualize it
C10	Tool's Strengths	"This prototype of the collaboratively built cartography unveiled the importance of deep observation and understanding of place." "The pictures and notes taken on the day, and the accounts brought by the historians and local residents, showed that the bay, with its shifting sands and mutable weather patterns, often defies modelling attempts, and, as one participant remarked, "does not behave the way it is supposed to." "Create a temporal, rather than a spatial, understanding of the environment that contains information about human and non-human presences, forces, and behaviors." "Such methods can contribute to a thick description of the urban landscape from a more-than-human perspective, embracing its many dimensions—from the celestial and meteorological to the material, affective, and imaginary."
C11	Tool's Limitations	"As an artefact, it was not easily transportable, and the wealth of information that it contained was impossible to categorize into a legible format without compromising the richness of the details embedded in handwritten notes and sketches."
C12	Recommendations	"It points to the importance of the process, rather than the outcome, of mapping when this is done with the purpose of developing a better understanding of place, and not of simply representing it."
C13	Location	England
C14	Year [a]	2018
C15	Additional Notes	"Historians, geographers, designers, environmental scientists, and some members of the local communities shared their knowledge and annotated the maps with their impressions and observations."

[a] If the timing of the study was not explicitly stated, the publication year was used as a "year" information.

invited people to interact with them (e.g. Nukabot [10]). Not all representations involved designers in their preparation. However, many settings included participants with an interest in specific nonhumans or contexts, such as urban gardening, sustainability, or plant-lovers. Overall, the representation teams include people from diverse disciplines, such as HCI, UX Design, VR, robotics, and theater, alongside people from various professions, including psychologists, homemakers, biologists, professors, entrepreneurs, therapists, regional inhabitants, policymakers, water engineers, farmers, agricultural engineers, and artists.

4.1.3 How are nonhumans involved? An account of some of the modalities already used in representation is as follows (Figure 3): visual (34 tools, e.g., [11, 37, 60]), auditory (9 tools, [10, 30, 55, 58, 70, 82, 88]), human body (3 tools, [50, 61, 81]), textual (2 tools, [76, 80]), tactile (2 tools, [5, 40]), and olfactory (1 tool, [40]). Auditory and human body modalities were used independently, whilst tactile and olfactory modalities appear in combination, such as visual & tactile (e.g., High Water Pants [5]), and visual & tactile & olfactory (e.g., Sensing Bodies [40]).

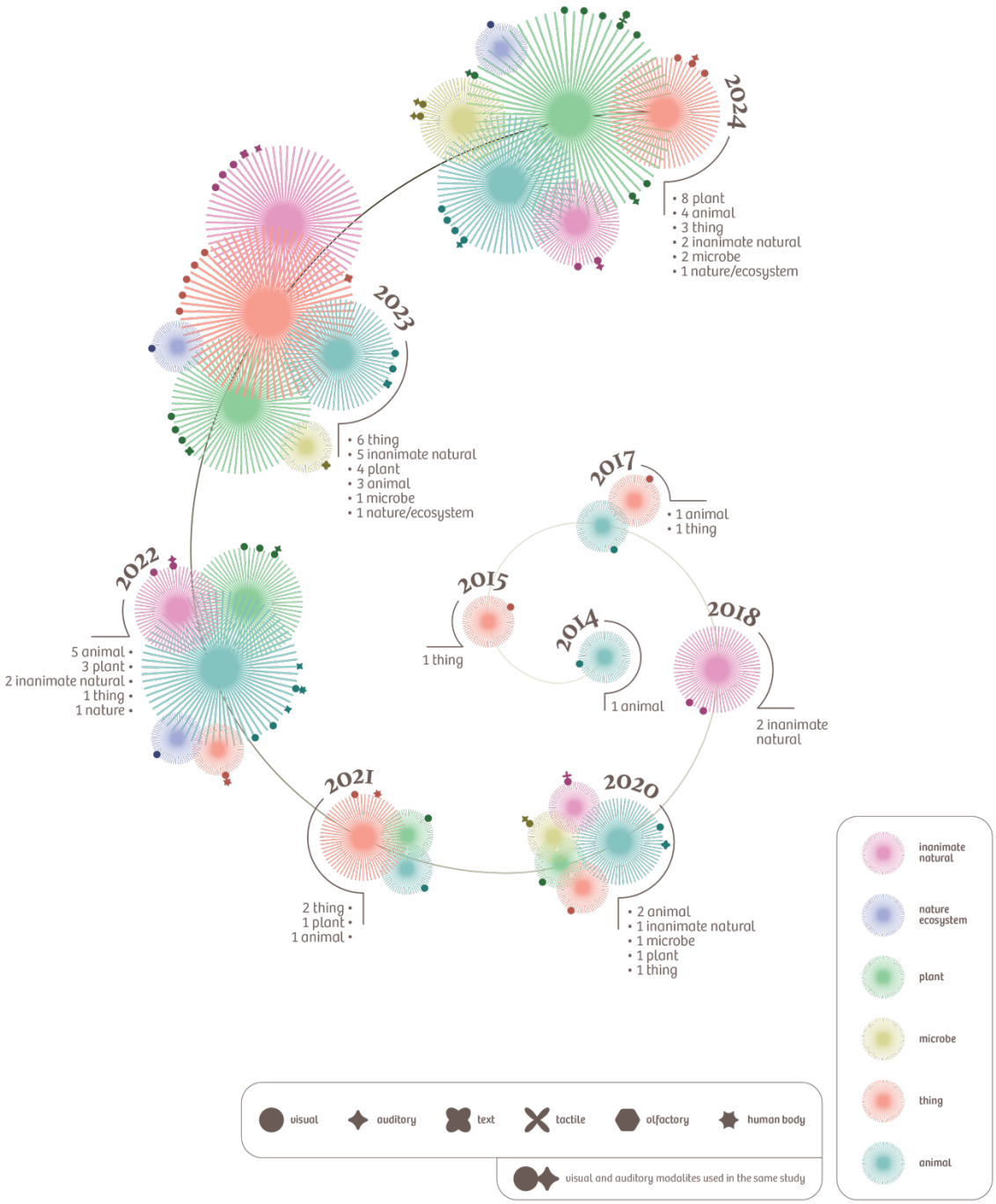


Figure 3: An account of some of the nonhumans already represented and modalities used in MTHD through the years

Data for the representation was collected through various methods, including ethnographic approaches (e.g., observations, expert interviews, workshops, and field notes), desk research, surveys, and sensors. The data included observational and behavioral information, such as photos, videos, and fieldnotes documenting nonhumans in their environments, as well as their behaviors, habitats, aspirations, frustrations, and interactions with their surroundings. Additionally, environmental and material data were collected, including measurements of high and low tides, soil phosphorus, nitrogen, and potassium levels, sea level changes, light, humidity, air pressure, and seasonal variations.

4.1.4 In what context does the representation take place? The studies in our corpus were conducted in a variety of countries across different regions. These include the United States (N:6), United Kingdom (N:5), Netherlands (N:5), Australia (N:5), Sweden (N:3), Denmark (N:3), Taiwan (N:2), China (N:2), Japan (N:1), and Turkey (N:1), among others. In total, the reviewed studies span 21 countries. Seven studies did not indicate the study location.

The purpose of the representation included fostering connections and empathy, as well as understanding nonhuman stakeholders and their relations with humans and their environment. By using sensors, some of the projects (e.g. Plant Listener [68]) aimed to reveal nonhuman experiences that cannot be naturally observed by humans. Furthermore, they aimed to challenge anthropocentric perspectives and encourage reflections on environmental concerns. By using representation tools, researchers also aimed to analyze, reflect on, and act within complex systems, identifying human and nonhuman stakeholders that constitute a system, encouraging a balanced view of the entities involved in or affected by a design intervention, and shifting the focus beyond end users to nonhumans that are impacted as parts of the system. Ultimately, they aimed to highlight the agency of nonhuman stakeholders and cultivate actionable knowledge to support inclusive design processes.

4.2 Parameters of representation tools in MTHD

4.2.1 Transferability. Transferability refers to how effectively a representation tool conveys insights about nonhumans to diverse audiences. A representation tool with a good level of transferability is accessible and clear for the diverse audience and captivates their attention. Accessibility ensures the tool is easy to engage with both physically (e.g., easily readable, smooth interaction) and cognitively (i.e., representation can be understood without requiring extensive expertise or prior knowledge). Clarity refers to the degree to which the tool's outputs are understandable without requiring additional explanation. Captivation highlights the tool's ability to create engagement and curiosity toward the represented nonhuman.

Representation tools with high transferability engage diverse audiences, such as novices, experts, and children, and help them understand various aspects of nonhuman perspectives. For instance, Under the Shade [82] uses ecological soundscapes to foster empathy for nonhumans, focusing on crows in urban environments. By observing crow behaviors and recording their vocalizations, the project created soundscapes that allow participants to experience the crow's world. The tool was successful from a clarity and captivation perspective. According to the authors, it helped to uncover winter roosting patterns of crows and provided a deeper insight into their behavioral patterns and communication methods. However, according to them, the tool was challenging to use because of the limited bird-watching experience of participants (the lack of accessibility perspective). Another example is Animal Persona [1, 19, 29], which was used in several studies for representing dogs, frogs, and chickens. This tool was successful both in clarity and accessibility. According to the authors of studies who utilized this tool, it provided a tangible and understandable medium for designers to focus on otherwise inaccessible users and ensured that stakeholder perspectives were identified and represented effectively, making the data actionable for design decisions. On the other hand, they pointed out that some unique experiences of nonhumans might be overlooked in favor of creating a more generalized persona that can address a broader range of nonhumans.

Tools with low transferability may fail to arouse audiences' interest. For instance, Plant Listener [68], a 3D-printed device resembling a garden torch, senses and monitors environmental conditions (such as light, nitrogen oxides, temperature, humidity, air pressure, and soil conditions) to inform gardening decisions. According to the authors of this study, the audience (even garden owners) showed little interest in the plant listener and associated app, perceiving it as a garden light and finding its functionality hard to understand without a detailed explanation. There was a lack of interest in the technical aspects of measuring nature and the audience found the tools disconnected from their concerns. Systems Mapping [78], a tool to support systems thinking is another example of low transferability of a representation. It involves creating visual representations (systems maps) of a system's components, with directional arrows that describe the effects (either positive or negative) one component has on another. Although the tool was successful in revealing entities and systems beyond the obvious ones affected by a design intervention, according to the authors, it was hard for people who had no experience with systems mapping as it required domain expertise and existing knowledge. Furthermore, it was challenging to decide when to stop looking for different stakeholders for those preparing the representation; they struggled to decide whether every stakeholder needed to be documented or how much detail would suffice. Therefore, the tool was lacking clarity and accessibility.

4.2.2 Depth of representation. Depth of Representation refers to the extent to which a representation tool conveys the complexities, behaviors, and relational and temporal dynamics of nonhumans. The tools can represent various information about nonhumans including general characteristics (e.g., appearance, overall behavior), temporal aspects (e.g., changes and patterns over time), and relational aspects (e.g. interactions with other entities). Accordingly, the depth of representation can be analyzed across three levels. Representations can include only one type of information (e.g. only general characteristics or relational aspects), surface level; they can combine two types of information (e.g. both relational and temporal aspects), Level 1; and they can integrate all three types of information, Level 2.

Tools with greater depth move beyond surface-level descriptions to provide a comprehensive understanding of nonhumans and their interactions within their environments. For instance, Sensing Bodies [40] is an interactive installation that uses biosensors and LEDs to engage with plants (indigo, tobacco, and rice, in this case) and their colonial history. According to the authors of this study, it helped visualize the dynamic interactions between plants and humans and highlighted the interconnectedness of human bodies and environments (relational aspects). Furthermore, it highlighted plants' history and how it is related to participants' cultures, experiences, and values (temporal aspects). Another example is Experience Map [90], adapted from the user journey map, used in a study to analyze the olive harvesting process. According to

Table 2: Parameters with their definitions and example studies

Parameter	Definition	Example Study
Transferability	How a representation tool communicates insights about nonhumans in ways that can be understood and engaged with by a range of audiences. This includes how clearly the tool conveys its message, how accessible it is without requiring prior expertise, and how it captivates the audience.	• *Under the Shade* [82] provides clear representation as it helps to "*discover the pattern of crows roosting in winter"* and captivating representation as it *"evokes positive emotions, inspires exploration of the more-than-human, and provokes deeper thought"*. • *Animal Persona* [1, 22, 34] provides clear representations as it *"enables the team members to have a shared understanding about the perspectives of frogs as a stakeholder"*.
Depth of Representation	How a representation tool attends to the complexity of nonhuman experiences, including their behaviors, relationships, and temporal patterns.	• *Experience Map* [90] provides a representation with depth as it includes temporal, behavioral, and relational aspects of olive trees. • *Systems Mapping* [78] provides a representation with depth as it includes relational aspects and characteristics of chair.
Transcendentality	How a representation tool fosters emotional resonance, empathy, or a sense of connection with nonhumans, and brings their agency and presence into focus.	*Nukabot [10]* enables transcendentality by fostering connections (e.g., *"noticing the evolution of the nukadoko", "they enjoyed voice interactions and grew more affectionate toward their nukadoko"*) and helping to recognize the agency (e.g., "*feeling the aliveness of the nukadoko"*).
Multi-perspective Integration	How a representation tool enables the exploration of multiple perspectives such as those of humans and nonhumans and supports transitions or connections between them.	*Photography* [42] helps to explore nonhuman and human perspectives by providing insights about nonhuman but also facilitating the designers to return to human perspective.
Scalability and Flexibility	How a representation tool can be adapted to different nonhuman entities, scales of application, or design contexts without losing its effectiveness or integrity.	• "*Dear Nature* [19] can be scalable to other contexts as it only requires pen and paper to design representations. • *Embroidering Together* [54] can be flexible as different nonhumans can be represented without changing the tool (i.e., without changing the process of embroidering).
Resource Investment	How extensively time, effort, expertise, and material a tool requires to be prepared and used meaningfully within the design process.	• *Posters & Zines* [60] needs low resource investment as it requires pens and papers to design representations. • *Tracing Tides* [59] requires high resource investment due to extensive fieldwork (e.g., walking through alleyways, trails, fields, and the beach to explore the different landscapes of the peninsula and taking field notes).

the authors, the tool helped designers identify the interactions between olive trees and farmers (relational aspects) and analyze olive harvesting as sub-processes such as preparation for harvesting, harvesting, and transportation (temporal aspects).

There are also tools with less representation depth as they focus on specific types of information. Embroidery Together [54] is a shared creative practice that combines the slow and reflective process of embroidery with collaborative dialogue. According to the authors, this tool helped them to understand their interconnections with plants by reflecting on how plants have cared for them and exploring their emotional relationships with plants (relational aspects). Another example is Tracing Tides [59], a cartography tool to map tides. With this tool, participants could understand the movements and behaviors of tides (general characteristics).

4.2.3 Transcendentality. Transcendentality refers to the ability of the tool to help the audience create meaningful emotional connections and promote an understanding of the nonhuman's agency. This parameter is about going beyond mere representation by i) fostering emotional connections and empathy towards nonhumans, ii) recognizing the nonhumans' capacity to act, respond, and influence

systems rather than portraying them as passive or objectified entities, and iii) providing a relational understanding and encouraging participants to see beyond anthropocentric perspectives.

Tools that excel in this parameter facilitate care by emphasizing the agency and autonomy of the nonhuman, highlighting their active role in shaping interactions and environments. For instance, Dirty Nails [58], a wearable ring, is a speculative soil-sensing tool, allowing users to insert their fingers into the soil while wearing the ring. It measures nutrient concentrations in the soil, such as phosphorus, nitrogen, and potassium, and presents the data through sound. According to the author, this tool created a curiosity and a sense of wonder towards the soil. Another example is Nukabot [10]. It is a technologically enhanced wooden bucket designed for fermenting vegetables, using sensors to monitor fermentation parameters like pH, temperature, and gas levels. Through a voice interface, Nukabot communicates its status, offers care instructions, and reminds users to stir the rice bran, and it features a blinking eye. According to the authors, it facilitated the understanding of the aliveness of nukadoko and created a sense of affection and sense of nurturing.

Furthermore, the tools with high transcendentality tend to have multimodal sensory engagement. For instance, Sensing Bodies [40] (relying on visual, tactile, and olfactory senses) embodies the sociopolitical histories and relationships between humans and plants, providing an interactive, sensory-based platform to explore MTH entanglements. According to the authors, the interpretive data displays facilitated emotional connections and reflections on personal and cultural relations with plants. Furthermore, learning about the plants' colonial histories helped them understand the plants' agency.

However, not all tools aim to foster connections or recognize nonhuman agency. For example, Actant Mapping [78] does not primarily focus on cultivating emotional connections; instead, it seeks to establish a foundation for representation by identifying less visible actors and providing an overview of the system. Similarly, tools like Plant Persona [90] and Animal Persona [1, 22, 34] have limited transcendentality arising from the inescapable use of anthropocentric lenses in their creation, which can result in insufficient recognition of agency and the unintended anthropomorphism of the nonhuman stakeholders they aim to represent.

4.2.4 Multi-perspective integration. Multi-Perspective Integration refers to how effectively a representation tool enables the understanding of multiple perspectives, including those of nonhumans. It is about the tool's ability to facilitate a continuous and fluid shift between perspectives, for instance, exploring the perspective of animals, transitioning to that of humans, and then considering the perspective of plants.

A tool that integrates multiple perspectives ensures that the interests, roles, and agency of nonhumans are highlighted alongside human considerations. It avoids reducing nonhumans to mere resources or background elements and instead places them as active participants in shared systems. Beyond this, it also helps the transition between human and nonhuman perspectives, highlighting the entangled stakeholders. Creating a balance in perspectives is essential for fostering mutual understanding and collaboration, allowing audiences to explore interconnectedness without prioritizing one perspective over the other, either human or nonhuman.

None of the representation tools identified in this study fully supports a continuous shift between perspectives. However, some tools facilitated the transition from a nonhuman perspective to a human perspective, such as Photography [42], which is a subjective tool for data collection and visualization. In [42], participants used cameras to document their interactions with their environments and experiences, transforming these visual captures into meaningful representations of "data" as they perceived it. As a result, they were able to understand plant's well-being (nonhuman insights). Moreover, they were prompted to reflect on the nonhuman perspective when photographing their cat, capturing it on a blanket in a relaxed state. This act demonstrates how they transitioned from observing the cat's perspective to incorporating it into their human perspective, using the insights gathered from the nonhuman experience to inform their actions (transition between human and nonhuman perspectives).

Tools that are lacking in multi-perspective integration fail to enable a continuous shift between perspectives, often limiting participants to a singular perspective, whether human or nonhuman. For instance, when using the Experience Map [90], researchers observed that the process was predominantly focused on the plant perspective up until the creation of the map, particularly during the plant interview and plant persona, which were used prior to the Experience Map. However, upon integrating the human perspective into the experience map, the nonhuman focus was disrupted, and participants struggled to return to the nonhuman perspective. This demonstrates that while the shift from the nonhuman to the human perspective was smooth, the reverse transition, from human back to nonhuman, posed significant challenges. As a result, the tool failed to facilitate a continuous shift between perspectives, highlighting its limitation in maintaining a balanced focus throughout the process. Another example can be Scenarios Envisioning [83], a tool that explores potential future interactions and relationships between humans and nonhumans, by crafting imaginative narratives. According to the authors, participants easily understood the qualities of plants by using this tool (nonhuman insights), however, the solutions proposed because of these scenarios often considered human benefit rather than designing for both humans and plants, which again indicates a lack of continuous transition between perspectives.

4.2.5 Scalability and flexibility. Scalability and Flexibility refer to how well a tool adapts to different contexts and scales of use. Scalability ensures a seamless transition from individual applications to larger community-level implementations, maintaining their relevance and effectiveness. Flexibility ensures the tool can be adapted to specific cultural, geographic, or environmental settings without losing its core functionality. Tools with high scalability and flexibility are valuable for fostering widespread engagement and adoption across diverse audiences and contexts.

One example of a highly scalable and flexible tool is Photography [42], as participants only need a camera, a wildly adopted tool around the world, to capture data. However, although capturing images of plants, animals, or objects is easy, when microorganisms

are involved, photography may not be a very flexible tool for working with every nonhuman. Another example is Dear Nature [19], a tool that uses data drawings, which are visual representations of personal, place-based observations. Since observation and data drawing can be done individually or on a larger scale, we can argue that it is a scalable tool. However, the tool has less flexibility in terms of covering various types of nonhumans since microbes' presence and behaviors are not as easily observed, unlike larger or more visible nonhumans (e.g., animals and plants).

Similarly, as mentioned earlier, Nukabot [10] is specifically designed to represent microbial activity through fermentation activities. While it can be scaled up for larger communities (e.g. allowing multiple individuals to manage the bucket), the entire setup would need significant modifications to represent a plant, making it less flexible. Another example is Embroidering Together [54]. Although it allows for the representation of various nonhumans through embroidery, it has low scalability. The activity requires a certain level of skill and practice, which not all participants may possess, making it hard to scale up. Additionally, embroidery is a time-intensive craft, demanding patience and effort that may not be practical for larger-scale implementations.

4.2.6 Resource investment. Resource Investment refers to how extensively a representation tool requires the time, effort, materials, and expertise required to design, implement, and use a tool effectively. Low-resource tools are easy to deploy and accessible to a wide audience, while high-resource tools may demand specialized equipment, technical application, skills, or significant time commitment. The balance of resource investment is important as a tool that requires significant resources but delivers limited insights may not be practical, while a tool that balances input with impactful outputs is more desirable.

One example of a low-resource tool is Posters & Zines [60], a tool for students to process and express their experiences in contact zones that are designated spaces where they engage with food systems. The creation of Posters & Zines only requires paper, pens, and printouts of the photographs taken during the contact zone exercise. Therefore, it can be argued that it requires minimal resources.

On the other hand, some representation tools may require extensive technology resources. For instance, designers need to have knowledge of VR to create a Virtual PAL Tiago Robot [65], a virtual model of a real-life robot in a mixed-reality stage to simulate its behaviors and interactions with humans in a supermarket setting, Similarly, Slooooooooooow [88] is an interactive IoT-based installation designed to explore the concept of slowness in human-plant interactions. It integrates the biological processes of plants, such as transpiration, to create a new way of experiencing the rhythms of plants and their impact on the home environment. The setup utilizes various hardware components, including a smart curtain system, a smart speaker, and environmental sensors. These components are specialized equipment and require technical expertise to assemble. Technological resources aside, some representation tools may require time-intensive field work for data collection. For instance, while using Tracing Tides [59], researchers had to collect data by walking through alleyways, trails, fields, and the beach to explore the different landscapes of the peninsula and collect notes to create a cartography of tides.

5 DISCUSSION

Representation tools in MTHD are instrumental in advancing our understanding of nonhuman perspectives, bridging human-nonhuman interactions, and fostering actionable knowledge in design. Our focused analysis of 40 MTHD studies revealed a wide variety of approaches to representing nonhumans in design. Some tools were developed for single nonhumans, such as specific plants, animals, or objects, while others were created to work across multiple kinds of nonhumans. The studies also demonstrate the use of diverse modalities such as visual, auditory, bodily, tactile, textual, and olfactory, each offering different ways to engage with and convey nonhuman presence and perspective. These tools range from minimal setups using paper and drawings to more elaborate configurations involving sensors and interactive installations. Together, they illustrate how nonhuman representation in MTHD spans a wide spectrum of forms, subjects, and methods, shaped by each project's specific contexts, goals, and disciplinary backgrounds.

Aside from giving an overview of representation tools in MTHD, this paper contributes to the literature by constructing six parameters of representation tools in MTHD, which include transferability, depth of representation, transcendentality, multi-perspective integration, scalability and flexibility, and resource investment. These parameters can be used as reference points to categorize the representation tools, assess their quality, and guide the development of new tools. In this section, we will discuss the potential applications of these parameters. Then, we will explain their didactic and interpretative nature as two distinct categories. Finally, we will define representation as a dynamic, multifaceted approach for fostering a deeper understanding and meaningful connections with nonhumans.

5.1 Using the parameters to classify, evaluate and guide the development of representation tools in MTHD

The parameters help in categorizing representation tools into broader groups based on their attributes. For example, one class of tools can include the ones requiring low resource investment but offering limited depth of representation, such as Photography [42], Nature Cards [63] or Doodle Away [46]. Another class of tools can include high-investment tools that provide rich insights, like Slooooooooooow [88], Sensing Bodies [40], or Virtual PAL Tiago Robot [65]. This classification can support researchers in selecting tools that align with their audience, nonhuman focus, skills, and available resources. For instance, low investment-low depth tools can be suitable for introductory contexts, particularly when the primary goal is to spark interest and familiarize participants with nonhuman representation. They can be ideal for engaging large, diverse audiences in workshops, awareness campaigns, or educational settings, especially when working with limited time, budget, or expertise. Conversely, high investment-high depth tools can be used for projects that require a comprehensive understanding

of nonhuman behaviors, relationships, or temporal dynamics, particularly in interdisciplinary collaborations or high-stakes design interventions like urban planning or conservation efforts.

As for using the parameters for tool evaluation, they can help assess the quality of representation tools across cases. Such an assessment will be useful in the future with the growth of the MTHD field and increased use of shared representation tools, although the tools are currently scattered, with very few being applied across cases. We can illustrate this with the Animal Persona tool, which was applied in three different studies in our corpus. Upon examining the insights from these studies, we observe that while [1] achieved a balanced outcome in terms of transferability and transcendentality, using the same tool, [22] leaned toward transcendentality with fewer transferable insights and [34] heavily emphasized transferability. When analyzing the data collection methods used in these studies, we find that both [1] and [22] combined nonhuman observation with interviews, whereas [34] relied on questionnaires collected from human companions. This difference suggests that [34]'s lack of engagement with nonhumans during the data collection phase may have contributed to its weaker transcendentality outcomes, as it did not facilitate direct interaction or observation of the nonhuman stakeholders. This example analysis also implies that although the same representation tool is used across different cases with different groups, the performance of this tool according to the parameters can vary due to the differences in data collection.

Lastly, the parameters can serve as guiding principles for the development of new representation tools in MTHD. Acting as desired qualities, they can provide researchers with a framework to refine and enhance their tools. For instance, the MTHD field is defined by entanglements, with both nonhumans and humans being inherently present in design problems. The concepts of MTH and decentralization do not imply focusing only on nonhumans but rather emphasize an equal focus on both nonhumans and humans [25, 69]. Therefore, it becomes important for tools in the MTHD process to support a continuous transition between different perspectives. Such tools can help ensure that solutions benefit both nonhumans and humans. Since we previously noted the lack of tools that support continuous transition in multi-perspective integration, this effort becomes highly relevant for the future of representation tools in MTHD.

Another opportunity can be on modalities. We observed a major focus on visual modalities in existing tools, likely because visual inputs are more easily interpretable, and humans heavily rely on visual insight. For example, [58] highlighted that audio alone is insufficient, as interpreting information becomes challenging when sound is the sole medium. While this limitation should be acknowledged, we also see that multimodal tools often achieve stronger transferability and transcendentality. Examples of such tools include Nukabot [10] and Sensing Bodies [40]. This highlights an opportunity to focus on multimodality in future tool designs.

5.2 Didactic vs. interpretative representation tools in MTHD

Our analysis showed that representation tools in MTHD exhibit a wide range of approaches and impacts, reflecting the diverse ways in which nonhuman perspectives can be integrated into design processes. Some tools, like Personas (e.g. [11, 34, 79, 90]), are didactic in nature. They work by collecting and presenting data in a clear and straightforward manner, ensuring accessibility for a wider audience that spans across novices and experts. These tools are good in clarity, effectively communicating key insights without requiring significant interpretive effort. They also tend to have 1 or 2 levels of depth, especially relational or temporal aspects. For instance, Virtual PAL Tiago Robot [65] provides information about both general characteristics and relational aspects between customers in the supermarket and the robots. Other examples include mapping tools such as Actant Mapping and Product Lifecycle Mapping [78], Experience Map [90], and Virtual PAL Tiago Robot [65]. These tools are particularly well-suited for contexts where immediate understanding and practicality are critical. Furthermore, considering time constraints in a design process, these tools are more accessible. However, their structured and direct approach often limits opportunities for deeper emotional engagement or exploration of the complexities of nonhuman agency.

On the other hand, interpretative tools demand a more active engagement from participants. Tools like Chromatography [24, 64], Dirty Nails [58], Sensing Bodies [40], Plant Radio [30], Slooooooooow [88], and Games [55] encourage participants to go beyond surface-level understanding by interpreting data in more complex and context-specific ways. These tools often require background knowledge, additional research, or iterative interaction to understand nonhuman experiences. While this can pose accessibility challenges, it also opens pathways for richer engagement. Participants are invited to engage with the ambiguities and relational complexities of nonhuman entities, fostering deeper empathy and a deeper understanding of nonhuman agency. Unlike didactic tools, interpretative tools often thrive on their openness, allowing users to form unique and personal connections with the representations.

This duality between didactic and interpretative tools reveals a key tension in MTHD: the balance between accessibility and depth. Didactic tools prioritize clarity and inclusivity, making them valuable for introducing nonhuman perspectives to diverse audiences. However, their simplicity may lack the transformative potential of interpretative tools, which stand out in creating emotional resonance and fostering critical reflection, even if they are less immediately accessible.

These two types of tools do not have to be mutually exclusive but complementary; a nonhuman representation may combine the strengths of both. Didactic tools can provide a foundational understanding, establishing accessibility and clarity, while interpretative tools can build upon this foundation, offering opportunities for deeper exploration and emotional engagement. This highlights the importance of selecting representation tools for specific goals, audiences, and contexts, ensuring that the nonhuman perspectives can be meaningfully incorporated into the design process.

5.3 Representation as a dynamic and multi-faceted tool for cultivating deeper understanding and connection with nonhumans

Representation in the HCD centers on conveying human needs, desires, and experiences. It works within a framework where human agency is implicitly understood and does not require acknowledgment. This process often feels familiar for designers and thus is taken for granted, relying on well-established tools like personas

that have become almost default choices for both designers and non-designers [67]. However, in MTHD, representation transcends these boundaries to include nonhuman stakeholders who have their agency, roles, and perspectives. This shift redefines representation in design, transforming it into a more dynamic and multifaceted process [26] that engages both cognition and emotion.

The relationship between users and design is not merely about the impact of user research but involves complex, mutual interactions between representations, the tools that carry them, and the people involved in the process [38]. Creating a user representation is not only about communication; it involves numerous decisions made by designers and researchers on behalf of the user. These include determining which questions to ask during data collection, how to frame those questions, which insights to prioritize, what medium to use for communication, and to what extent personal and subjective interpretations of the designers are integrated into the representation. Similarly, in the context of nonhuman representation, questions about who will represent nonhumans, the criteria for selecting these representatives, and how they will be engaged remain open [3].

In line with this perspective, we argue that in the field of MTHD, representation requires an intentional acknowledgment of the agency of nonhumans by those creating the representations. This is the first critical step: recognizing nonhumans as active stakeholders rather than passive objects within systems. Following this, the process continues with creating empathy, an emotional connection that allows designers and participants to relate to nonhuman stakeholders.

Representation in MTHD is not a detached step in a design process that aims to synthesize data; it becomes a conscious act of bridging gaps between human and nonhuman worlds. This act reflects a broader need to decenter human perspectives, shifting the focus toward relationality and mutual interactions. Decentering, in this sense, is not framed as an ultimate goal but rather as a continuous process [52] that evolves with each interaction. As a result, creating nonhuman representations transforms into a relational practice that shapes how we perceive and coexist with nonhumans. This transformation shifts representation from a static step into a dynamic process of discovery and engagement, where tools serve as facilitators of deeper inquiry rather than merely passive vehicles for conveying data.

This expanded perspective applies even to nonhumans we are familiar with, such as domesticated animals or cultivated plants. While we may believe we understand them well, much about their experiences, needs, and agency often remains unknown. Representation in MTHD challenges these assumptions, pushing us to engage with nonhumans as distinct entities with their agency and preferences. Tools like Plant Radio [30] and Product Lifecycle Mapping [78] exemplify this by not only displaying data but also revealing the limitations of our knowledge and compelling us to go back, learn more, and expand our understanding of nonhuman agency, relationships, and perspectives.

Representation, in this sense, is not just a means of conveying information but a tool for cultivating deeper understanding and connection. Tools like responsive installations Sensing Bodies [40] and Plant Radio [30] exemplify this shift. Unlike human representations, which often convey explicit and familiar messages, nonhuman representation invites participants to grapple with unfamiliar forms of existence and interconnectedness. As [52] argues, discomfort is a "necessary component of decentering practices". Similarly, our analysis showed that the representation tools in MTHD actively confront participants with the gaps in their understanding of nonhuman worlds, emphasizing the evolving and relational nature of representation. By embracing diverse ways of understanding and engaging with technology or other species, grounded in the coexistence of multiple perspectives and the recognition of pluriversal values [26], this process moves beyond anthropocentric paradigms, compelling humans to rethink their relationships with nonhumans and the systems they inhabit. It also challenges designers to embrace uncertainty, recognizing that effective representation is not just about synthesizing what is already known but about continually uncovering and integrating what has been overlooked.

6 CONCLUSION

MTHD facilitated a transition in design research and practice, expanding the concept of user to include nonhuman stakeholders. In this paper, we analyzed 40 MTHD studies to provide an overview of representation tools according to the nonhumans they represent, the modalities they use, data collection techniques, the type of data, and the context of the representations. As a result of our analysis, we identified 41 different tools representing a variety of nonhumans, including animals, plants, microbes, inanimate natural, and things. These tools utilized a range of modalities such as visual, auditory, olfactory, tactile, and human body and engaged with data derived from both environmental sensors and ethnographic methods. The studies were situated across diverse geographic locations and disciplinary settings, with representations created by individuals and groups from various professional and cultural backgrounds. The purposes of these tools varied, including efforts to foster empathy, surface nonhuman experiences, and challenge anthropocentric assumptions.

We also constructed six key parameters of representation in MTHD, which are transferability, depth of representation, transcendentality, multi-perspective integration, scalability and flexibility, and resource investment, and showed that they can be used to classify, evaluate, and guide the development of representation tools in MTHD. By leveraging these parameters, we can enable the design of better representation tools and more mindful use of existing ones. This involves understanding where these tools fall short on MTHD contexts and finding ways to address those gaps, recognizing the contexts in which they are most appropriate, and critically evaluating how they account for nonhuman perspectives. Such an approach ensures that their use remains fair and respectful of nonhuman perspectives.

7 LIMITATIONS AND FUTURE WORK

This paper presents an exploratory literature review, offering a curated and interpretive account of how nonhuman stakeholders have been represented through tools in MTHD. Rather than aiming for comprehensive coverage, this exploration focuses on examples that include user representation.

Our selection strategy was guided by our focus on representation, particularly as it relates to the concept of the "user" in design. We prioritized search terms such as "more-than-human", "nonhuman", and "non-human", which speak more directly to the idea of representing nonhuman users. Broader philosophical terms like "posthuman" or "multispecies" were not included in the search criteria as they often engage with ontological or epistemological perspectives rather than with tools or practices of representation. As such, we acknowledge that relevant studies from other domains such as critical theory, STS, or anthropology may not appear in our corpus, even if conceptually related.

While the review introduces six parameters to characterize representation tools in MTHD, we did not attempt to map each tool against all parameters. This decision was because not every paper in our corpus provided reflections or information related to every parameter. As a result, we used illustrative examples to introduce the parameters and highlight their practical relevance. Future work could build on this initial set of parameters by organizing workshops with researchers and practitioners to collaboratively evaluate tools. Such an effort could help further validate the parameters, identify gaps, and support their application in tool development and selection.

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