

The Significance of Aristotle's Four Causes in Design Research

Boris Hennig, Matthias Rauterberg

- 1 Nigel Cross, "Designerly Ways of Knowing," *Design Studies* 3, no. 4 (1982): 221–27.
- 2 S. A. Grave, "Aristotelian Philosophy and Functional Design," *Australasian Journal of Philosophy* 28, no. 1 (1950): 29–42; James Wang, "The Importance of Aristotle to Design Thinking," *Design Issues* 29, no. 2 (Spring 2013): 4–15; Lauri Koskela et al., "The Aristotelian Proto-Theory of Design," in *An Anthology of Theories and Models of Design*, ed. Amaresh Chakrabarti and Lucienne T. M. Blessing (London: Springer, 2014), 285–303.
- 3 Bruce Archer, "Systematic Method for Designers," in *Developments in Design Methodology*, ed. Nigel Cross (Chichester: John Wiley & Sons, 1984), 57–82, 59.
- 4 Richard Buchanan, "Thinking about Design: An Historical Perspective," in *Handbook of the Philosophy of Science*, ed. Dov M. Gabbay et al., vol. 9 (Amsterdam: Elsevier, 2009), 409–53, 433.
- 5 Shirley D. Gregor and David Jones, "The Anatomy of a Design Theory," *Journal of the Association for Information Systems* 8, no. 5 (2007): 317; Dirk S. Hovorka and Shirley D. Gregor, "Untangling Causality in Design Science Theorising," in *Information Systems Foundations: Theory Building in Information Systems*, ed. Dennis N. Hart and Shirley D. Gregor (Canberra: Australian National University E Press, 2012), 59; Matthias Rauterberg and Loe Feijs, "Enhanced Causation for Design," *International Journal of Philosophy Study* 3 (2015): 22–25.
- 6 See Wang, "The Importance of Aristotle to Design Thinking," 8.
- 7 René Spitz, "'Design Is Not a Science': Otl Aicher's Constitutional Putsch at the HfG Ulm and His Credo for the Social Responsibility of Designers," *Design Issues* 31, no. 1 (Winter 2015): 7–17.

Introduction

Designers rely on scientific knowledge. When they design physical objects, they need to know things about physics and engineering. When they design user interfaces, they need to know about machines and human psychology. Beyond these bits of knowledge that designers may borrow from other disciplines, there is what Cross calls "designerly knowledge."¹ The picture of the world associated with such designerly knowledge appears to be rather Aristotelian.² For instance, Archer writes that "design involves a prescription or model, the intention of embodiment as hardware, and the presence of a creative step."³ As Buchanan points out, we can see Aristotle's four causes lurking in the background.⁴ The model corresponds to Aristotle's formal cause, the prescription to his final cause, mention of embodiment and hardware introduces the material cause, and the creative step hints at the presence of someone who makes this step, which is, in Aristotle, the efficient cause. Others have made similar connections.⁵ If they are right, designerly knowledge is deeply entrenched in an Aristotelian worldview. Natural science, however, has long since abandoned Aristotelian metaphysics.⁶ Does this mean that designerly knowledge is necessarily unscientific?

One might answer this question by attempting to show that and how design as a discipline can be based entirely on modern science. Alternatively, one might conclude that design is an art and not a science. Spitz describes a typical controversy at the Hochschule für Gestaltung in Ulm between advocates of these two approaches.⁷ A third option is to argue that designerly knowledge is a mix of art, engineering, and various scientific disciplines. This creates the danger that design as a discipline gets lost "down a black hole of plurality."⁸ A fourth possible response might be attractive: to argue that design constitutes a domain where applying Aristotelian ideas and concepts is not unscientific.

We aim to contribute to the fourth sort of response. We begin by arguing that when properly understood, Aristotle's four causes apply to all living beings. Second, we argue that these four causes are tightly connected to one another in living beings, whereas they come apart in artifacts. Third, we show that the dismissal of final and formal causes in early modern science and philosophy was

facilitated by a (mis)conception of nature as a divine artifact. Finally, in a more positive spirit, we offer a sketch of how the formal and final causes of artifacts derive from the formal and final causes of the living beings that make and use them. We argue that artifacts are what they are because they occupy a certain place in the life of living beings. Consequently, one cannot understand designerly knowledge without appealing to Aristotle's four causes.

Aristotle's Four Causes

Aristotle defines natural things as those that have in themselves a principle of motion and rest.⁹ What he has in mind is the following: For natural things, there is a principle that determines which changes or states of remaining unchanged are in accordance with their nature and which ones are not.¹⁰ As a slogan, natural things are things for which things are natural. Living beings, for instance, are such that certain kinds of food are healthy for them, others are not; certain movements are characteristic of them, others are not. Thus, healthy cows eat grass, healthy humans don't, healthy sparrows fly, and healthy penguins don't.

Before asking whether and why Aristotle's four causes apply to all living beings, it is essential to note that although "cause" is our best translation of the term(s) Aristotle uses (*aitia* and *aition*), he does not mean what we usually mean by "cause."¹¹ Although the best way of approximating what Aristotle means by "cause" is via the notion of an explanation, not all explanations are causal in the modern sense of this term. One may explain what a meme is, how an astrolabe works, what shoelaces are for, who painted *The Calling of St. Matthew*, or what molasses is made of. None of these explanations need to have any implications as to why a thing happens, exists, or is what it is. If we know that Caravaggio painted the *Calling*, for instance, we know who did it, but we still do not know why. For Aristotle, that something has a cause means that it admits of some sort of explanation, in this very general sense of explanation.

Now for the four causes. To know the causes of a natural thing, says Aristotle, is to be able to explain (1) what it is made of, (2) what it is, (3) where it came from, and (4) where it is headed. He does not refer to these causes as "material," "formal," "efficient," and "final"; these labels were introduced later by his commentators. In *Physics* II 3, he lists them as follows:

- 1) "that out of which as a constituent a thing comes to be,"
- 2) "the form or model" or "the account of what the thing would be,"
- 3) "the primary source of the change or the staying unchanged," and
- 4) the "end," "that for the sake of which," the "good," or the "best."¹²

8 Rachel Cooper, "Design Research—Its 50-year Transformation," *Design Studies* 65, no. C (2019): 14.

9 Aristotle, *Physics* II 1, 192b13–14.

10 See Boris Hennig, *Aristotle's Four Causes* (New York: Peter Lang, 2019), 16–19.

11 Michael Frede, "The Original Notion of a Cause," in *Essays in Ancient Philosophy* (Minneapolis: University of Minnesota Press, 1987), 125–50.

12 Aristotle, *Physics* II 3, 194b23–35, quoted from William Charlton's translation: Aristotle, *Physics Books I and II* (Oxford: Clarendon Press, 1970).

How are these causes linked to the notion of a thing that changes or remains unchanged in accordance with or against its nature? That all changing things must be analyzable into matter and form follows from Aristotle's account of change. If nothing about a given situation remained the same, we would have no reason for saying that a thing changed, as opposed to being replaced by an altogether different thing. Therefore, for a thing to change, there must be some continuity and some discontinuity. In most of the cases that Aristotle describes, what changes is the form of the thing. But it is also possible that a thing exchanges its matter.¹³ In either case, there must be some contrast between matter and form for it to be true that the thing changes.

When Aristotle describes the formal cause of a thing as "the account of what it would be," he has a specific sort of change in mind: the change that a living being undergoes, for instance, when it changes out of a seed or embryo into a fully developed exemplar of its species. The formal cause of a kitten is the sort of thing (*Felis catus*) that it comes to be when it grows up and all goes well.

There can be no change without matter and form, but in addition to these, there must be something that initiates and drives the change, as it were. This is the efficient cause. We take it that most readers find this claim immediately plausible. What is less commonly acknowledged is the following. First, it does not make sense to speak of anything as initiating or driving a change unless this thing does something specific: this, as opposed to that. Second, whenever a thing does something specific, what it does is necessarily directed at some perhaps minimal and immediate aim. As a consequence, whenever the efficient cause is initiating a change, what it does must be directed at something specific. For Aristotle, what it is directed at is the final cause. This means that there can be efficient causation without teleology.

Here is another way of bringing this out. In an influential paper, Machamer and colleagues define mechanisms as "entities and activities organized such that they are productive of regular changes from start or set-up to finish or termination conditions."¹⁴ If this is what mechanisms are, there can be no mechanisms unless processes have termination conditions. We wish to argue that termination conditions are in fact a species of final causes. They are called termination conditions because when they are met, a process terminates. This means that as long as the process has not yet terminated, they cannot yet have been met.

To say that an ongoing process has such termination conditions is therefore to suggest that as long as it is still going on, certain things may be expected to happen in the immediate future. If something is in the process of pushing another thing, it must be doing something with the anticipated result that the other

13 Aristotle, *Physics* I 7, 190a14–16 and 190b8–9.

14 Peter Machamer, Lindley Darden, and Carl F. Craver, "Thinking about Mechanisms," *Philosophy of Science* 67, no. 1 (2000): 3.

thing gets pushed. If a kitten is in the process of growing into a cat, it must be undergoing a change of which the anticipated result is the cat.

Such anticipations may be frustrated, of course. When this happens, something that looked like an ongoing process is in fact no longer going on at that point. But our anticipations about what is going to happen in the immediate future cannot always be false unless it is always false to say that a process is currently going on.

A world without final causes would be a world in which nothing is ever directed at any aim. This world would contain no natural things in Aristotle's sense, no ongoing processes, and no mechanisms in Machamer's sense. That we do not live in such a world is clear, we think, from the fact that no entire aimless sequence of events would deserve the name "life." Whatever we might do in such a world, it could not qualify as living in it. It might not even qualify as doing anything.

This step completes the overall argument. If there are things for which specific ways of changing and developing are natural, then these things must be analyzable into (1) matter and (2) form, there must be (3) something that initiates and directs their development, and there must be (4) something toward which their development is directed. In this sense, all four Aristotelian causes must apply to all natural things.

Living Beings

We are now going to show that in living beings, the four causes are so intimately connected as to be almost indistinguishable. More specifically, all of them are tied to the formal cause, that is, to the form (or range of forms) into which living beings develop when they develop into complete and mature instances of their species. The following section contrasts living beings with artifacts, where the connection among the causes is much less tight.

Aristotle argues that the most general point of what living beings do throughout their lives is to preserve and perpetuate their own life form.¹⁵ In this sense, the formal cause of a cat, *Felis catus*, is also the ultimate final cause of what cats do. Furthermore, the efficient cause of any living being is another instance of the same form. Humans, Aristotle likes to say, come from other humans.¹⁶ He writes: "What a thing is, and what it is for, are one and the same, and that from which the change originates is the same in form as these."¹⁷

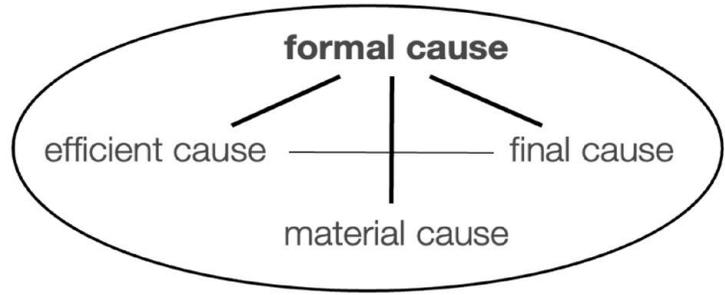
Aristotle leaves out matter, but there are good reasons for thinking that the organic matter of living beings is closely tied to their form. When living beings take in matter, they transform and absorb it to a point where it ceases to be whatever it was before and

15 Aristotle, *De Anima* II 4, 415a22–b7.

16 Aristotle, *Physics* II 2, 194b13.

17 Aristotle, *Physics* II 7, 198a25–26.

Figure 1
Aristotle's four united causes of living beings.



turns into an organic part of their body. The organic matter of living beings, such as flesh, bones, tissues, and bodily fluids, would not exist in this form without the living beings that are made from them. This tight connection makes it difficult to clearly separate the organic matter of a living being from its form.¹⁸

If all this is so, the organic matter of living beings is inseparable from their form, their ultimate final cause is the preservation and perpetuation of their form, and their efficient cause is another instance of their form (see Figure 1).

Artifacts

It is significant that living beings naturally come to be via re-production. This means that their efficient cause, the being that brought them into existence, is a being of the same kind. Artifacts, in contrast, can and usually do come into being through production (without the re-). For example, humans come out of humans, but fishing nets do not come out of fishing nets. In typical cases of production, living beings impose forms other than their own onto things that would not naturally take on this form on their own. Thus, there is a sense in which the form of artifacts is external to them.

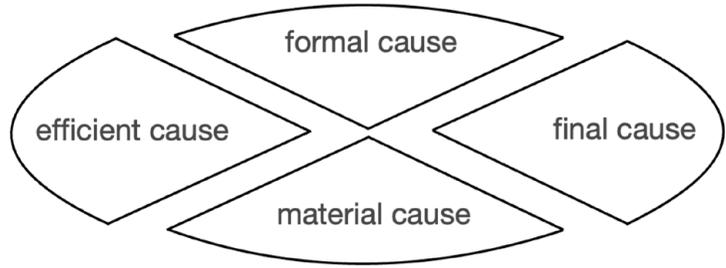
In many cases, to be sure, there is still a sense in which the form of an artifact is present in its maker: not in the body of the maker but in their mind. However, not even this need be the case. The designer and the maker of an artifact need not be the same person, so the maker need not mentally represent what they are making. Moreover, the form of a product might not even be represented in the mind of any living person at all but be implicitly present in a certain mode of production.

This means that there is no good reason for denying that spider webs are artifacts. Although spiders do not mentally represent the form of the webs they make, this form is implicitly present in certain specific patterns of instinctual behavior. In any case, fishing nets and spider webs do not have the same form as their efficient causes.

18 Aryeh Kosman, "Substance, Being, and Energeia," *Oxford Studies in Ancient Philosophy* 2 (1984): 121–49, 143; Christopher Frey, "Organic Unity and the Matter of Man," *Oxford Studies in Ancient Philosophy* 32 (2007): 167–204; Boris Hennig, "Form and Function in Aristotle," *History of Philosophy & Logical Analysis* 23, no. 2 (2020): 317–37.

Figure 2

The four separable causes in artifacts.



The form and matter of artifacts are less tightly linked. The same sorts of artifacts may often be made of different kinds of material,¹⁹ and this material is rarely absorbed to the degree to which food is transformed into organic matter. Because of this, it makes a lot more sense to say that a beaver dam is made of wood and mud than to say that a beaver is made of flesh and bones. Beaver dams are made by putting wood and mud together, but beavers are not made by putting flesh and bones together.

For these reasons, artifacts are usually a lot less unified than living beings (see Figure 2). This loose connection is why Aristotle routinely refers to artifacts when explaining his doctrine of the four causes. He is not suggesting that the causes primarily apply to artifacts, as some think.²⁰ Instead, he gives artifacts as examples because, in these cases, it is easier to tell the four causes apart.²¹

Nature as an Artifact

Many early modern philosophers and scientists have rejected natural teleology. Bacon writes that the final cause “distorts the sciences except in the case of human actions.”²² Descartes warns us not to be so arrogant as to suppose that we know nature’s aims.²³ Spinoza claims that “final causes are nothing but human fancies.”²⁴ We argue that this was prepared and made possible by a reinterpretation of nature as an artifact.

When Aristotle emphasizes that humans come from humans, he does so in explicit opposition to the idea that nature was created by a divine artificer. He argues that teleology is intrinsic to nature itself. As we have argued, his final causes are simply the termination conditions of natural processes, and therefore, there can be teleology in the absence of an intelligent designer.

When Jewish, Christian, and Islamic thinkers adopted Aristotelianism, they had no place for natural teleology. They had already started from the assumption that all of nature had been created by a divine being. They assumed that the human and the divine mind are not part of nature. On this basis, they assumed that Aristotle’s four causes apply to natural things in the same way they apply to tables and chairs. In their view, the ultimate efficient cause of all natural things is a supernatural thing, which imposes

19 Kathrin Koslicki, “Four Eighth Hephaistos: Artifacts and Living Beings in Aristotle,” *History of Philosophy Quarterly* 14, no. 1 (1997): 78.

20 For example, Martin Heidegger, *The Question Concerning Technology and Other Essays*, trans. William Lovitt (New York, London: Harper & Row, 1977), 11–12; Simon J. Evnine, *Making Objects and Events: A Hylomorphic Theory of Artifacts, Actions, and Organisms* (Oxford: Oxford University Press, 2016), 161.

21 Koslicki, “Four Eighth Hephaistos,” 79.

22 Francis Bacon, *The New Organon* II 2, ed. Lisa Jardine and Michael Silverthorne (Cambridge: Cambridge University Press, 2000), 102.

23 René Descartes, *Principia Philosophiae* I 28, in *The Philosophical Writings of Descartes*, trans. John Cottingham et al., vol. 1 (Cambridge: Cambridge University Press, 1985), 202.

24 Baruch Spinoza, *Ethics I*, Appendix, ed. and trans. Matthew Kisner and Michael Silverthorne (Cambridge: Cambridge University Press, 2018), 37.

a form onto matter with a certain purpose in mind. They concluded from this that both efficient and final causes are extrinsic to nature.²⁵ Nature, in turn, appears as inert matter trapped in between a divine act of creation and a divine purpose. Natural things no longer move by themselves, because nothing can move toward an end unless it is either itself intelligent or passively moved by an intelligent agent.²⁶

As a result, natural things were conceived of as mere artifacts. Hobbes begins his *Leviathan* by identifying nature with the art by which God made the world.²⁷ Descartes ends his *Principia Philosophiae* by refusing to make a distinction between natural bodies and artifacts.²⁸ Natural bodies thus cease to satisfy Aristotle's definition of natural beings. Their traits are imposed on them by an external cause, so they no longer have an internal principle of motion and rest. Therefore, natural beings lose their unity, and teleology ceases to be natural.²⁹ This conception of nature as an artifact remains in place when we substitute the supreme artificer with a blind watchmaker.³⁰

The point of this foray into the history of ideas was to make clear that Aristotelian teleology in its original form does not involve or require the idea of an intelligent designer. Nowhere does Aristotle suggest, as Ingold thinks, that all form is "imposed by an agent with a particular design in mind."³¹ This idea is not Aristotelian at all; it is Christian. Aristotle had no reason for thinking of nature as an artifact, because for him, natural teleology was more fundamental than artifact teleology.³² In his view, natural teleology makes artificial teleology possible, because ultimately, artifacts are what they are by occupying a certain place in the life of natural beings, becoming part of their habitat.

From Living Beings to Artifacts

Let us now, in an Aristotelian spirit, situate artifact teleology in natural teleology. One might think that Aristotle's four causes apply to artifacts to the extent to which they apply to the actions from which they result. This thought, however, leads to a dead-end, because it is not at all clear whether all four causes apply to actions. It has been a matter of some debate, for instance, what the material cause of an action might be. Killeen thinks it is the substrate within which the action happens,³³ Reece postulates that it is the body of the agent.³⁴ Natali and Evnine argue, somewhat more plausibly, that the material cause of a given action is the sum of steps that are involved in it.³⁵ Aristotle's answer is clearly that processes and events, and hence also actions, have no material causes at all. He claims that movements, developments, and changes cannot undergo further movements, developments, or changes. If they did, he argues, one would have to assume that they are made of matter, which would not make sense.³⁶

-
- 25 See Robert Wisnovsky, "Towards a History of Avicenna's Distinction Between Immanent and Transcendent Causes," in *Before and After Avicenna*, ed. David C. Reisman (Leiden: Brill, 2003), 49–68.
- 26 Aquinas, *Summa Theologiae* Ia 2,3 c.a.
- 27 Thomas Hobbes, *Leviathan*, ed. Edwin Curley (Indianapolis: Hackett, 1994), 3.
- 28 Descartes, *Principia Philosophiae* IV 203, 288.
- 29 Margaret J. Osler, "From Immanent Natures to Nature as Artifact: The Reinterpretation of Final Causes in Seventeenth-Century Natural Philosophy," *Monist* 79, no. 3 (1996): 388–407.
- 30 Richard Dawkins, *The Blind Watchmaker* (New York: Norton, 1996).
- 31 Tim Ingold, *Making: Anthropology, Archeology, Art and Architecture* (London: Routledge, 2013), 37.
- 32 See *Physics* II 2, 194a21–22: Art Imitates Nature.
- 33 Peter R. Killeen, "The Four Causes of Behaviour," *Current Directions in Psychological Science* 10, no. 4 (2001): 137.
- 34 Bryan C. Reece, "Aristotle's Four Causes of Action," *Australasian Journal of Philosophy* 97, no. 2 (2019): 213–27, 216.
- 35 Carlo Natali, "Actions et mouvements chez Aristote," *Philosophie* 2, no. 73 (2002): 32; Evnine, *Making Objects and Events*, 220.
- 36 Aristotle, *Physics* V 2, 225b14–16 and 226a10–14.

This means that there is no general reason for assuming that everything that comes out of living beings has all of the four causes. Even so, although it might be a matter of controversy whether all four causes apply to the behavior of living beings, it is fairly clear that they all apply to all or most of the things that living beings make. What appears to be less clear is why and how artifacts come to have formal and final causes.

According to a surprisingly popular view, artifacts have their form and purpose because designers and makers impose a form and a purpose onto them when they make them. John Symons, for instance, says that “artifacts are what they are by virtue of the intentions of their designer.”³⁷ Although this is not false, it is not very illuminating either. The activity of making an artifact is usually guided by an idea of what to use it for. To come up with the best design for a knife, for instance, designers are well advised to look at how people use knives and what they use them for. The intention of the designer is thus not the sole and final authority because her design ought to be guided by the use of the artifact. This is one reason why there can be badly designed things.³⁸ Also, artifacts may acquire uses for which they were not originally designed, which may significantly change their role in the life form they belong to.³⁹ In these cases, artifacts may acquire formal and final causes against the intentions of their designers.

Instead of thinking of artifacts only as the intended results of productive activity, we should probably think of them more generally as somehow embedded in a specific form of life.⁴⁰ What artifacts are is shaped by their designers, makers, and users, as well as the discourse and culture surrounding their design, production, and use. They are what they are by virtue of occupying a specific place in a particular form of life.

It might still make sense to say that an artifact is an “impress of mind onto matter,” as Evnine likes to put it.⁴¹ However, it might be better to generalize this idea a little further and say that an artifact is an impress of a life form onto matter. When a fisher makes a net, for example, she may impress her mind onto matter, but unless spiders have minds, this is not what happens when they make webs. In these cases, a portion of matter gets caught up in the life of a living being, such as to constitute a part of its controlled habitat rather than a part of its organism. This is, most generally, what artifacts are: things that are in some sense external to the organic body of a life form, yet part of its life because their production and use have a certain place in this form of life.⁴²

Artifacts are, as it were, parts of the extended body that some living beings build around their organic bodies.⁴³ This means that the distinction between artifacts and living beings is more

-
- 37 John Symons, “The Individuality of Artifacts and Organisms,” *History and Philosophy of the Life Sciences* 32, nos. 2/3 (2010): 244.
- 38 See Don Norman, *The Design of Everyday Things*, rev. ed. (New York: Basic Books, 2013), ch. 1.
- 39 Beth Preston, “Of Marigold Beer: A Reply to Vermaas and Houkes,” *British Journal for the Philosophy of Science* 54 (2003): 601–12; Kathrin Koslicki, *Form, Matter, Substance* (Oxford: Oxford University Press, 2018), 220–37.
- 40 See Ron Wakkary, *Things We Could Design: For More Than Human-Centered Worlds* (Cambridge, MA: MIT Press, 2021), ch. 3; Peter-Paul Verbeek, *What Things Do: Philosophical Reflections on Technology, Agency, and Design* (University Park: Pennsylvania State University Press, 2005), 235. See also Pertti Saariluoma, José J. Cañas, and Jaana Leikas, *Designing for Life: A Human Perspective on Technology Development* (London: Springer, 2016), ch. 6.
- 41 Evnine, *Making Objects and Events*, 177.
- 42 See Tim Ingold, *The Perception of the Environment: Essays on Livelihood, Dwelling, and Skill* (London: Routledge 2000), 347.
- 43 See Karl Marx, “Ökonomisch–philosophische Manuskripte,” in *Marx Engels Werke, Ergänzungsband*, vol. 40 (Berlin: Dietz, 1968), 515–16. See Boris Hennig, “Self-Knowledge, Estrangement, and Social Metabolism,” *Monthly Review* 70, no. 10 (2019): 40–57.

fluid than one might expect. As Ingold shows, a conception of artifacts resulting from a premeditated imposition of form onto inert matter is misleading in many cases.⁴⁴ Furthermore, if artifacts are extensions of organic bodies, “the standards of natural organs should be applied to such artificial organs.”⁴⁵ This is why the four causes apply to artifacts as well as to natural organisms.

Conclusion

We have argued that Aristotle’s four causes apply to living beings. Such beings are divisible into matter and form, they originate from a source, and their development is subject to certain natural success criteria. In living beings, these four causes are tightly connected: the matter of living beings cannot be separated from their form, their parents are instances of this same form, and the aim of their development is this form. In contrast, artifacts receive their form and purpose from beings that differ from them, so their formal and final causes are external to them. We further argued that the idea that final causes are supernatural rests on the idea that nature was created and designed by an intelligent being. Finally, we contrasted this picture of living beings as artifacts with a positive account, according to which artifacts are extensions of living beings. If we are right, artifact teleology depends on natural teleology.

We return to the question we raised in the beginning—whether designerly knowledge is necessarily unscientific—by noting that to make sense of what designers do, one must make sense of the artifacts they design. Since Aristotle’s four causes, adequately understood, apply to all living beings and by extension to the artifacts that living beings make, all four causes are essential for understanding and articulating what designers do. There can be no designerly knowledge without an understanding of Aristotle’s four causes. And there is no reason why this would make such knowledge any less scientific. Aristotle’s four causes do not rest on an outdated conception of causality, according to which unrealized goals or forms would have some odd kind of causal effect. Instead, his idea is that to understand living beings, one must ask how they develop and change—that is, what they are, what they are made of, where their development originates, and where it is headed. These are perfectly legitimate, scientific questions, and Aristotle’s four causes correspond to four kinds of equally legitimate and scientific answers to such questions.

44 Ingold, *Making*, 45.

45 André Leroi-Gourhan, *Gesture and Speech* (Cambridge, MA: MIT Press), 91.

Contributors

Kaja Tooming Buchanan is Professor of Design Theory, Practice and Strategy and Director of the Experience Design Research Lab in the College of Design & Innovation at Tongji University, China. She works in complex organizational environments with a special focus on experience design, user research, design theory and strategy. Her interest lies in creative projects that impact organizations and society at large, especially the experience of people in social interaction in complex social and cultural environments. She received her PhD in Design from the Faculty of Fine, Applied, and Performance Arts at Göteborg University, Sweden in 2007. She has lectured and taught in universities around the world and received more than twenty cultural and research grants and awards.

Hugh Dubberly manages a software, service, and systems design firm in San Francisco. He teaches systems design in the Interaction Design Program (MDes) at California College of Art, and design theory in the Information Design and Data Visualization Program (MFA) at Northeastern University, where he is Professor of Practice. Previously, he was Vice President of Design at Netscape and managed Creative Services and brand at Apple.

Rachel Hellgren is a design educator with a background in visual communication and design management and co-designer of this *Design Issues* cover (vol. 38, no. 4 Autumn 2022). She composes the Books Received annotations for *Design Issues* and provides pre-production consultation for selected submissions of the journal's cover designs. Rachel is a visiting assistant professor in the Emerging Technology, Business, and Design department at Miami University in Oxford, Ohio, where she teaches courses in visual design principles, design research, and interaction design. Her interests include both BIPOC land practices and pedagogies.

Boris Hennig has studied Philosophy, Logic, and Theory of Science in Leipzig, Germany. He authored *Aristotle's Four Causes* (New York: Peter Lang, 2019), as well as many papers about historical and systematic topics in philosophy. He is Associate Professor for Ancient Philosophy at Toronto Metropolitan University.

Paul Kahn is a lecturer in the Information Design and Data Visualization program at Northeastern University. He currently leads the COVIC project. He has previously been active in hypertext research and design agencies in the US and France offering services in information architecture, interface design, and experience design. Currently, he lectures and writes about information design history.

Jeffrey Kruth is co-designer of this *Design Issues* cover (vol. 38, no. 4 Autumn 2022) and an assistant professor in the Department of Architecture & Interior Design at Miami University in Oxford, Ohio. There, he works closely with the Miami University Center for Community Engagement in Over-the-Rhine and teaches courses on urban design, theory, and critical practice.

Marzia Mortati is an associate professor in Service Design at the Design Department of Politecnico di Milano. She is Vice-Director of the International Master in AI for Public Services and one of the executive directors of the European Academy of Design. Her research focuses on the design process, service design, public sector innovation, and new technologies. She has worked on numerous international research projects collaborating with researchers all over the world.

Matthias Rauterberg received a BS in Psychology (1978), a BA in Philosophy (1981) and a BS in Computer Science (1983), an MS in Psychology (1981) and in Computer Science (1986, Germany), and a PhD in Computer Science/Mathematics (1995, Switzerland). He has over 500 publications in international journals, conference proceedings, books, etc.

Dario Rodighiero works at the intersection of knowledge design, critical data studies, and digital humanities. He is an assistant professor of Sciences and Technology Studies at the University of Groningen, serving the multidisciplinary faculty Campus Fryslân. He is affiliated at Harvard University with metaLAB and the Berkman Klein Center for Internet & Society. With Metis Press, in 2021 he authored *Mapping Affinities: Democratizing Data Visualization*—a book about charting scientific communities from a design-driven, ethical perspective.

Aggie Toppins is Associate Professor and Chair of Design at the Sam Fox School of Design and Visual Arts at Washington University. She works at the intersections of studio practice and critical writing to explore how visual communication bears on social realities. Toppins is interested in the appraisal of history, the negotiability of meaning-making, and in using these critical orientations to decouple design from universalist narratives of capital. She has published in *Design and Culture*, *AIGA Eye on Design*, *Slanted*, and *Baseline Shift: Untold Stories of Women in Graphic Design History*.

D Wood has an MFA in furniture design from the Rhode Island School of Design and a PhD in Design Studies from the University of Otago, New Zealand. She is an independent craft scholar whose artist profiles and exhibition reviews have appeared in an international roster of art and design publications. Wood is the editor of *Craft is Political* (Bloomsbury Visual Arts, 2021).