Biotechnology Design

www.cambridge.org/bdn

Systemic perspective on contemporary biodesign

Bert Vuylsteke, Jan Detand and Francesca Ostuzzi

Industrial Systems Engineering and Product Design, Ghent University Faculty of Engineering and Architecture, Belgium

Full Paper: Biodesign Conference

Cite this article: Vuylsteke B, Detand J, and Ostuzzi F (2026). Systemic perspective on contemporary biodesign. *Biotechnology Design*. **4**, e54, 1–15. https://doi.org/10.1017/S2977905726100638

Received: 27 February 2026 UTC
Revised: 5 May 2026 UTC
Accepted: 22 May 2026 UTC

Keywords:
Biodesign advancement; systems thinking; systemic design; industrial design engineering technology

Corresponding author:
Bert Vuylsteke;
Email: bert.vuylsteke@ugent.be

Abstract

Biodesign is increasingly recognised as a promising life-centred design field, yet its implementation within Industrial Design Engineering Technology remains limited. This study investigates the research question: "*What systemic structures hinder advancement of biodesign?*". Drawing on extensive interviews with 21 pioneering biodesign experts ($n = 21$) and qualitatively analysed through a systems-oriented perspective, the findings reveal that barriers are not isolated practical issues but rooted in deeper systemic structures across several system depths – from competencies to agency, design briefs, tools and processes. Four constraining systemic structures were identified: limits to growth (accessibility), eroding goals (expectations of biodesign projects), growth and underinvestment (invest in biodesign competencies) and tragedy of the commons (knowledge restrictions in biodesign). Together, these indicate that biodesign's limited advancement stems from systemic misalignment rather than technological immaturity. The study advocates coordinated systemic interventions at deeper system depths to enable cumulative, long-term advancement of the biodesign field.

Impact statement

By revealing the systemic structures that hinder the advancement of biodesign, this study provides a foundation for developing coordinated, practice-enabling infrastructures and tools that can strengthen the field's advancement across academia, individual designers, design agencies and industry. Its systems-oriented insights support more effective integration of regenerative, life-centred design approaches, contributing to the broader transition towards a more sustainable and circular economy.

Introduction

As the global need to shift towards sustainability increases, design practices in Industrial Design Engineering Technology need to evolve beyond traditional, techno- or human-centred approaches, as acknowledged in multiple design fields, that is, ecodesign, biomimicry, biodesign, etc. (Ceschin and Gaziulusoy 2016). This article is specifically focused on the field of biodesign and how it is concurrently enacted as a design field within Industrial Design Engineering Technology. Biodesign, although rising, is today still little implemented by industrial design engineers in their projects. Even though many initiatives are out there, and still being developed, its advancement seems to remain obstructed in some way or another. Hence, this study sets-out to analyse pioneer biodesign experts' experience to learn if there are deeper systemic structural explanations to be found for this obstruction. This is addressed by extensively interviewing 21 pioneer biodesign experts ($n = 21$) to ask why and how they already engage with biological elements in their design projects. More specifically what challenges and opportunities, as well as what obstacles/barriers & advantages/enablers they experience. The interview transcriptions are subsequently qualitatively analysed, applying the QUAGOL protocol, through a coding process. The codes specific to the challenges and opportunities, and obstacles/barriers & advantages/enablers are used to identify a system of biodesign and its underlying systemic structures that might hinder its advancement in Industrial Design Engineering Technology. Creating this initial understanding of the hindering systemic structures might enable future work to use this knowledge of these identified systemic structures to pinpoint leverage points through which biodesign can be meaningfully advanced.

Theoretical foundations

This section will address the growing foundations of the biodesign field, the recognition of multi-species agency in design, the changing role of designers and a systems thinking approach employed to deal with the complexity – such as biodesign implementation in Industrial Design Engineering Technology.

© The Author(s), 2026. Published by Cambridge University Press. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

The biodesign field

In this study, the argument advanced by Thomsen and Tamke (2022) – that learning from nature alone is insufficient to achieve a genuine transition towards circular and regenerative systems – is explicitly adopted (Thomsen and Tamke 2022). Biodesign is therefore positioned not as an evolution of biomimicry that merely translates biological inspiration into existing industrial paradigms, nor as the commodification of natural resources, but as a design approach that actively collaborates with (once-)living biological systems. Rather than treating nature as a passive reference or extractable input, biodesign engages ecosystems as co-creative partners that sustain both human and non-human life (Kopnina 2017; Shiva 2000). In this sense, it operates "beyond biomimicry," as articulated by Myers (2018a), by embedding design practice within ecological processes rather than abstracting from them (Myers 2018a).

The ethos of biodesign resonates with what has been described as *"organic design"*: an approach that involves *"watching objects grow"* and *"letting nature, the best among all engineers and architects, run its course"* (Antonelli 2018, p. 7; Birch *et al.* 2024). Within this study, biodesign is defined following the formulation proposed by Biofabricate as *"Designing of, with, and for biology"* (Antonelli 2018; Birch *et al.* 2024; Lee *et al.* 2020, p. 10). This concise definition captures the breadth of biodesign practice and foregrounds the varying roles that biology can assume within design processes.

Biodesign is not confined to a single industry but is increasingly applied across architecture, construction, cosmetics, fashion, fragrance, colouring, automotive design and other industries (Myers 2018b). Across these domains, a defining characteristic is the integration of (once-)living organisms as active participants in design processes (Ginsberg and Chieza 2018). Oxman (2016) observes that contemporary design is increasingly incorporating biological processes not merely as sources of inspiration, but as contributors to utility and behavioural transformation (Oxman 2016). Yet, such integration introduces significant challenges for Industrial Design Engineering Technology. Biological systems are characterised by heightened variability, unpredictability and uncertainty, which often conflict with conventional expectations of control, standardisation and repeatability.

Although biodesign moves beyond conventional biomimicry, it still draws upon core biomimetic principles as methodological and evaluative foundations. In aligning with *Life's Principles* and foundational biomimetics concepts, biodesign reframes design as *life-centred* rather than exclusively human-centred, applying biological forms, processes and ecosystem logics to address complex challenges (Stevens *et al.* 2022). Within material economies, biodesign contributes to regenerative practices in the Circular Economy (Cotsaftis *et al.* 2023). As du Plessis (2012) argues, regenerative paradigms emphasise co-creative partnerships with nature grounded in adaptation, resilience and regeneration (du Plessis 2012). Biodesign thus mediates between material systems, living processes and socio-ecological contexts, positioning itself as an enabler of the regenerative transformation.

Rise of agency

The emergence of biodesign is closely linked to broader debates surrounding the Anthropocene – an epoch defined by the dominant influence of human activity on planetary systems (Crutzen 2002, 2022). As critiques of anthropocentrism have intensified, alternative framings such as bio- or symbiocentrism have been proposed, repositioning humanity as an integral participant within ecological systems rather than as an external controller (Albrecht and Van Horn 2016; Pollini and Rognoli 2024). This shift carries profound implications for design.

Design has traditionally been described as a *"human tradition of inquiry and action"* concerned with intentionally creating preferred situations, the *"ultimate particular"* (Nelson and Stolterman 2014, pp. 1, 31). Implicit in this framing is the assumption that agency resides solely within human actors. The rise of More-Than-Human (MTH) thinking challenges this assumption. First articulated by Abram (1996), the MTH perspective decentres humanity and recognises ecosystems, plants, fungi, animals, soils, atmospheres and technological artefacts as active participants in design processes (Abram 1996). Conventional paradigms often treated these entities as passive resources to be extracted, optimised or controlled – a reflection of a mechanistic worldview that separates humans from ecological systems (Cole 2012; Pataranutaporn *et al.* 2020). In contrast, MTH perspectives emphasise interdependence, recognising that agency is distributed across interconnected actors.

Agency, understood as the capacity to meaningfully influence outcomes, thus extends beyond human stakeholders. In biodesign, this expansion manifests as *non-human biological agency*: the active contribution of (once-)living organisms or biological materials to design processes. *More-Than-Human Design* has emerged as a field that intentionally creates space for such non-human agency to influence outcomes in mutually beneficial ways (Karana *et al.* 2023; Kim 2021; Wakkary 2021).

Theoretical grounding for MTH agency in biodesign is further articulated by Gough and colleagues, who draw from Human–Computer Interaction (HCI) to propose living computational systems (Gough *et al.* 2020, 2021a, 2021b). Rather than relying solely on digital computation, these approaches recognise biological organisms as contributors of bioaffordances – organism-specific capacities for action and interaction (Gough *et al.* 2021b). Building on Gibson's (1977) concept of affordances and its adaptation by Norman (1988) to Industrial Design (Gibson 1977; Norman 1988), bioaffordances describe the action possibilities offered by non-human biological agents. From this perspective, biodesign emerges as *the application of bioaffordances*, enabling symbiotic collaboration between biological and design entities (Gough *et al.* 2021b).

The integration of MTH agency inevitably raises ethical considerations. Armstrong (2022) emphasises that when living agents are engaged in design processes, they must be appropriately supported, calling on designers to *"step inside the skin"* of the entities they work with (Armstrong 2022, p. 5). Her principles advocate recognising microbes as foundational architects of the biosphere, shifting designers' roles from sole authors to facilitators within multi-species collectives, fostering metabolic enlivening rather than extractive optimisation and integrating diverse knowledge systems beyond modern science (Armstrong 2022). These principles foreground reciprocity, stewardship and dialogue with biological systems.

Taken together, the rise of expanded agency in biodesign is characterised by: explicit acknowledgement of agency beyond the human, commitment to reciprocity and stewardship, alignment of MTH lifecycles with product and system lifecycles and engagement with local ecologies through iterative, open-ended practices that embrace variability, unpredictability and uncertainty. In doing so,

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

biodesign spans from translating nature into industrial forms to co-producing value with (once-)living ecosystems (Pollini and Rognoli 2024).

Changing role of designers

As agency expands beyond the human, the role of the designer undergoes a profound transformation too. Designers have shifted from being mere material applicators – selecting and specifying predefined materials – to material collaborators/orchestrators who coordinate complex material systems that include living and once-living entities (Gough *et al.* 2020; Vuylsteke *et al.* 2023). This shift reflects an increasing engagement with processes of growth, transformation, decay and regeneration across extended temporal scales (Camere and Karana 2018; Välk *et al.* 2023).

Recognising non-human biological agencies as stakeholders fundamentally alters the design landscape. Designers must navigate intricate networks of interdependent actors, increasing systemic complexity and requiring nuanced understanding of dynamic interactions between human and non-human agents (Camere and Karana 2018; Dade-Robertson and Zhang 2024; Karana *et al.* 2023). Agency no longer resides solely in human intention nor in autonomous biological processes, but emerges through their relational entanglement (Gough *et al.* 2021a; Karana *et al.* 2023; Oxman 2016).

This shift challenges the conventional pursuit of control, predictability and optimisation. Instead, designers are called to cultivate acceptance of open-endedness and uncertainty, embracing the variability inherent in ecological systems (Karana *et al.* 2023; Kim 2021; Ostuzzi 2017). The designer's role becomes less about prescribing fixed outcomes and more about initiating conditions for interactions to unfold (Dubberly and Pangaro 2015; Myers 2018a).

To engage meaningfully with MTH agents, designers must adopt transdisciplinary approaches, integrating knowledge from biology, biotechnology, biochemistry, ecology, botany and related life sciences (Bandoni *et al.* 2022; Camere and Karana 2018; Chen *et al.* 2023; Kääriäinen *et al.* 2020; Myers 2018c; Pollini and Rognoli 2024). In this expanded role, designers move from controlling matter to co-evolving with (once-)living systems.

This transformation – from human-centred problem solver to systems initiator and orchestrator within multi-species collectives – forms a critical theoretical foundation for understanding biodesign. It situates design not as an external force imposed upon nature, but as a relational practice embedded within living ecologies.

System-oriented perspectives and systemic design

As is illustrated with the broad and ever-emerging academic and industrial discourse in biodesign, its complexity is rising with the increased understanding. In order to address this complexity of the field and its practice in Industrial Design Engineering Technology, approaches are employed that are specifically well suited to handle this wicked context (Vandenbroeck 2012).

Therefore, this study aligns with and extends prior research that recommends systems thinking and systemic design to handle complexity (Vandenbroeck 2012). Dubberly and Pangaro (2023), for instance, recently present multiple recommendations for scholars working with systems, supported by practical examples (Dubberly and Pangaro 2023). Similarly, Dumon and Ostuzzi (2021) reports the use of systemic design in design education through practice-based assignments, providing empirical evidence of systemic design being integrated into academic curricula and offering a robust platform that resonates with such recommendations (Dumon and Ostuzzi 2021). Wiek *et al.* (2011) further argues that systems thinking and systemic interventions are among the key competencies in sustainability (Wiek *et al.* 2011). McMahon and Hadfield (2007) likewise advocate systems thinking as a pathway towards sustainable design solutions by proposing a taxonomy for systemic design and testing their assumptions with professional designers, challenging them to think in systems when addressing a given problem (McMahon and Hadfield 2007).

Across these contributions, a core lesson emerges that motivates this study: through systemic design – spanning across design fields – designers can push projects beyond symptomatic solutions that remain confined to isolated products and instead intervene in the interconnected conditions that shape practice and its outcomes.

Furthermore, does the Law of Requisite Variety in Cybernetics tell us that *"only variety can destroy variety"* (Ashby 1956, p. 207). Following this law, two strategies arise to address the increased experienced variability, unpredictability and uncertainty when biodesigning: (1) reducing the variety of the system to be controlled by simplifying it, something that we have done by refraining from biodesign principles over the last decades, (2) increasing the variety of the designer (controller) rather than reducing the variety of the system, thereby increasing the adaptive capacity of the designer through a meaningful support system. Of course, before this second strategy can be implemented we need to identify what hinders advancement to date.

Ultimately, this study is guided by the following research question: *"What systemic structures hinder advancement of biodesign?."*

Methodology

In order to answer this study's research question, pioneering biodesign experts were interviewed. The data obtained is very extensive, to the extent that in total three studies evolved from this large dataset alone. Each using the data obtained from: (1) responses of a specific set of questions within these interviews, (2) different angles of reconfiguring this qualitative data. This paper will report on one of these studies, focused on a specific set of questions. Figure 1 illustrates the complete methodological process for this study.

Phase 1 – Participant selection and recruitment

A systematic digital search (using Google search engine and LinkedIn post search) was conducted to identify projects and organisations operating within the field of biodesign. To ensure the relevance of the sample, three inclusion criteria were applied:

1. The core activity of the project or company engages with biodesign, verified by the presence of multiple key descriptors – as illustrated in the Biodesign Model – on their digital platforms (bioart, bioeconomy, bioassembly, biobased, biobased economy, biocomposite, biodegradable, bioderived, biodesign, biofabrication, biogenic, bioinspired, biological, biomanufacturing, biomass, biomaterial, biomimicry, biophilia, bioplastic, bioreceptivity, biorefinery, biosynthesis, biosynthetic, biotic, bodily material, compostable, ecosystem, green economy, growing design, marine degradable, material ecology, microorganism, natural, organic, regenerative design,

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

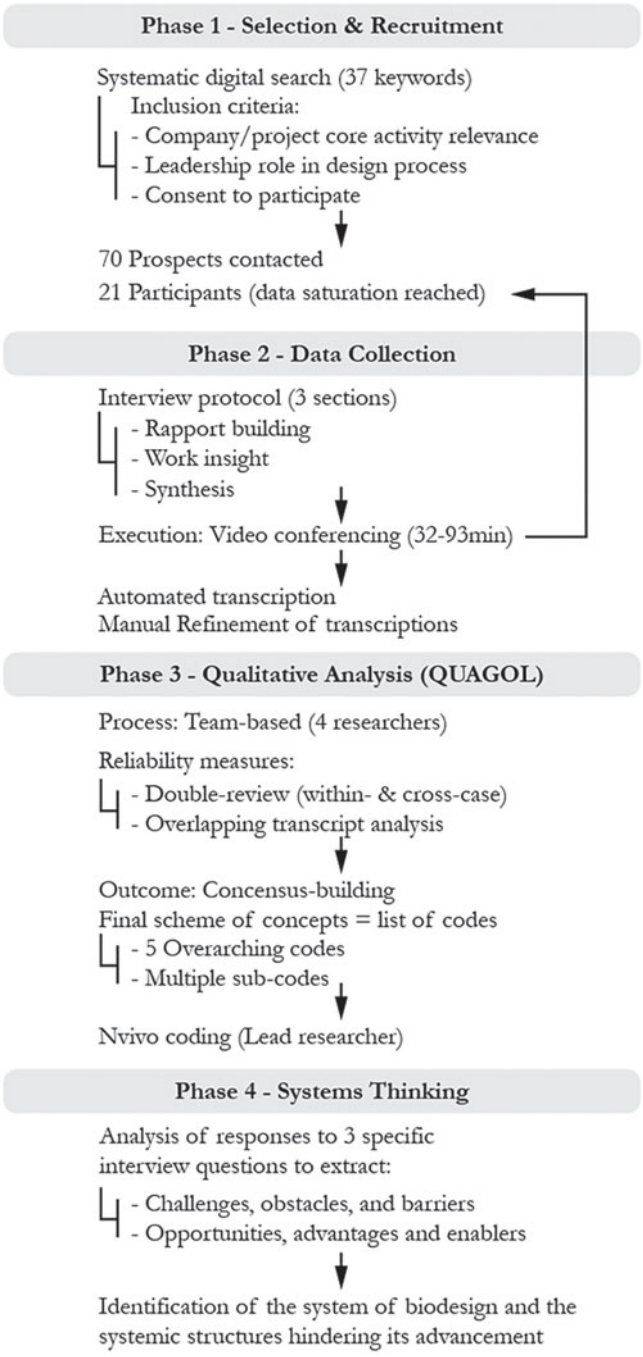


Figure 1. Methodological process overview.

renewable material, synthetic biology), which were studied in a prior study on terminology (Vuylsteke *et al.* 2023);
2. The prospective participant had to hold an active or leadership role in the biodesign process; and
3. A willingness to participate in the study.

70 candidates were identified and contacted to participate. Recruitment continued until data saturation was reached, defined as the point at which no new themes or insights emerged in subsequent interviews. The final sample – constituting 21 expert participants ($n = 21$) – was deemed sufficient given the depth of the interviews and the strong thematic convergence observed across the data, which indicated that significant and diverse insights could be derived from participants' reported experiences. Table 1 provides an overview of these biodesign expert participants, highlighting a diverse range of professional backgrounds and geographical locations.

To ensure relevance across the contexts in which biodesign is enacted, the studies defined and targeted four distinct audience groups that biodesign on different scales and with different purposes: academia, individual designers, design agencies and industry with R&D departments.

- *Academia* is defined here as the collective world of higher education, research and scholarship, encompassing professors, researchers and students who are dedicated to the pursuit and preservation of knowledge in Industrial Design Engineering Technology.
- *Individual designers* are defined as freelance professionals who are self-employed and work in service of a larger company or project.
- *Design agencies* are defined as collectives or teams of designers with specific specialisations working in service of larger companies or projects.
- *Industry with R&D departments* is defined as companies that have specialised departments of designers, architects, engineers and/or bioengineers who pursue novelty within the company's niche.

These four target audiences were also made explicit in the tabular overview of the biodesign expert participants. Some participants were attributed to multiple target audiences. Of all participants, 28% were involved in academia, 57% as individual designers, 10% in design agencies and 38% in industry with R&D departments.

Phase 2 – data collection

An interview protocol was established and validated (https://doi.org/10.6084/m9.figshare.26206817) (Vuylsteke *et al.* 2022a), consisting of three distinct phases:

1. 4 opening questions to establish rapport;
2. 10 questions providing insight into the participants' specific work; and
3. 10 closing questions designed to broaden the scope of the discussion and facilitate a synthesis of the interview.

All interviews were conducted in English by the lead researcher via video conferencing (using MS Teams), with durations ranging from 32 to 93 minutes. Audio recordings were transcribed automatically and subsequently refined manually to ensure accuracy.

Phase 3 – qualitative data analysis

The study employed the Qualitative Analysis Guide of Leuven (QUAGOL) methodology to ensure a rigorous and transparent interpretive process (Dierckx de Casterle *et al.* 2012). The method entails a, preparatory phase followed by an actual coding phase. In the preparatory phase, all transcripts were subjected to thorough re-reading. Reliability was supported through two specific measures: first, each interview was randomly assigned and reviewed by at least two researchers to ensure overlap and verify consistency in interpretation; and second all researchers reviewed the interview once *within-case* (interview by interview) and once *cross-case*

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

Table 1. Overview of biodesign expert participants

Interviewee acronym	Job title	Target audience	Expertise in	Country of origin	Country based	Biodesign projects
A.F.	Product design intern	Individual designer	Product design	Poland	Belgium	A chair seat made of a biocomposite from offal (bones and blood).
A.E.	Biodesigner	Individual designer	Product design	Turkey	Turkey	A water-resistant commercial soap packaging made of artichoke leaves.
A.C.	Astrobiology researcher	Academia	Product design	US	US	Materials made from food waste.
B.M.	Product/fashion designer	Individual designer	Product design	Poland	Poland	A chair seat made of a biocomposite from offal (bones and blood).
C.Mo.	Materials science engineer/sustainable materials research consultant	Academia	Material design	US	US	Biologically derived polymer research.
C.Mc.	Designer/researcher/ assistant professor	Individual designer/ academia	Product design	US	US	A raincoat made from algae-based polymer.
C.W.	Grant recipient as integrated designer	Individual designer	Material design	Germany	Germany	Textile dyeing process using pigment producing bacteria.
C.T.M.	Research assistant	Academia	Fashion design	Spain	UK	Bio-engineered silk.
F.A.	Founder/designer	Industry R&D	Product design/ Fashion design/ Social design	Brazil	Brazil	Natural rubber derived jewellery products.
I.P.	Founder/designer	Industry R&D	Product design	Thailand	Germany	Flower waste-based packaging.
J.A.	Future materials research fellow	Individual designer/ academia	Microbiology/ product design	US	UK	Mushroom-based pigments for cosmetics.
J.R.	Material researcher/ designer	Industry R&D	Material design	UK	UK	Sunflower-based textiles.
K.L.	Founder/designer/ architect	Industry R&D	Architecture	US	Denmark	Seagrass thatching.
K.B.	Lecturer/PhD Candidate	Individual designer/ academia	Product design	South Africa	South Africa	Biobased birds' nests for endangered species.
L.W.	Material expert	Individual designer/ design agency	Product design	Germany	Germany	Developing a material from sugar beet bagasse.
L.U.	Junior design engineer	Individual designer/ industry R&D	Product design/ material design	Germany	UK	Colour printing with algae.
M.M.	Founder/designer	Industry R&D	Product design/ material design	Italy	Italy	Mycelium-based wall cladding and flooring.
M.K.	Founder/designer	Individual designer/ industry R&D	Product design	India	The Netherlands	Foot ware from fallen palm leaves.
M.S.	Designer	Individual designer	Product design	The Netherlands	UK	Seaweed-based packaging.
O.Y.	Founder/designer	Industry R&D	Fashion design	China	China	Fruit waste-based fashion items.
S.L.	Founder/designer	Individual designer/ design agency	Product design	Israël	The Netherlands	Gutta Percha polymer application.

(question by question) to mitigate order bias. Each researcher produced narrative interview reports that captured the participant's storyline and key meaning and created a conceptual interview scheme containing preliminary concepts and their relationships (Figure 2).

The team subsequently compared and synthesised individual schemes, resulting in a joint conceptual scheme that established seven overarching codes and associated subcodes (Figure 3) (Vuylsteke *et al.* 2022b).

The actual coding phase was supported by NVivo software (Lumivero 2022). The seven overarching codes and their respective subcodes were imported as a preliminary codebook. The relevant interview fragments were linked to the appropriate codes, introducing emergent subcodes where novel commonalities appeared, and concepts were analysed in detail.

This study adopted a systems-oriented research approach in order to analyse the response specific for the following three interview questions:

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

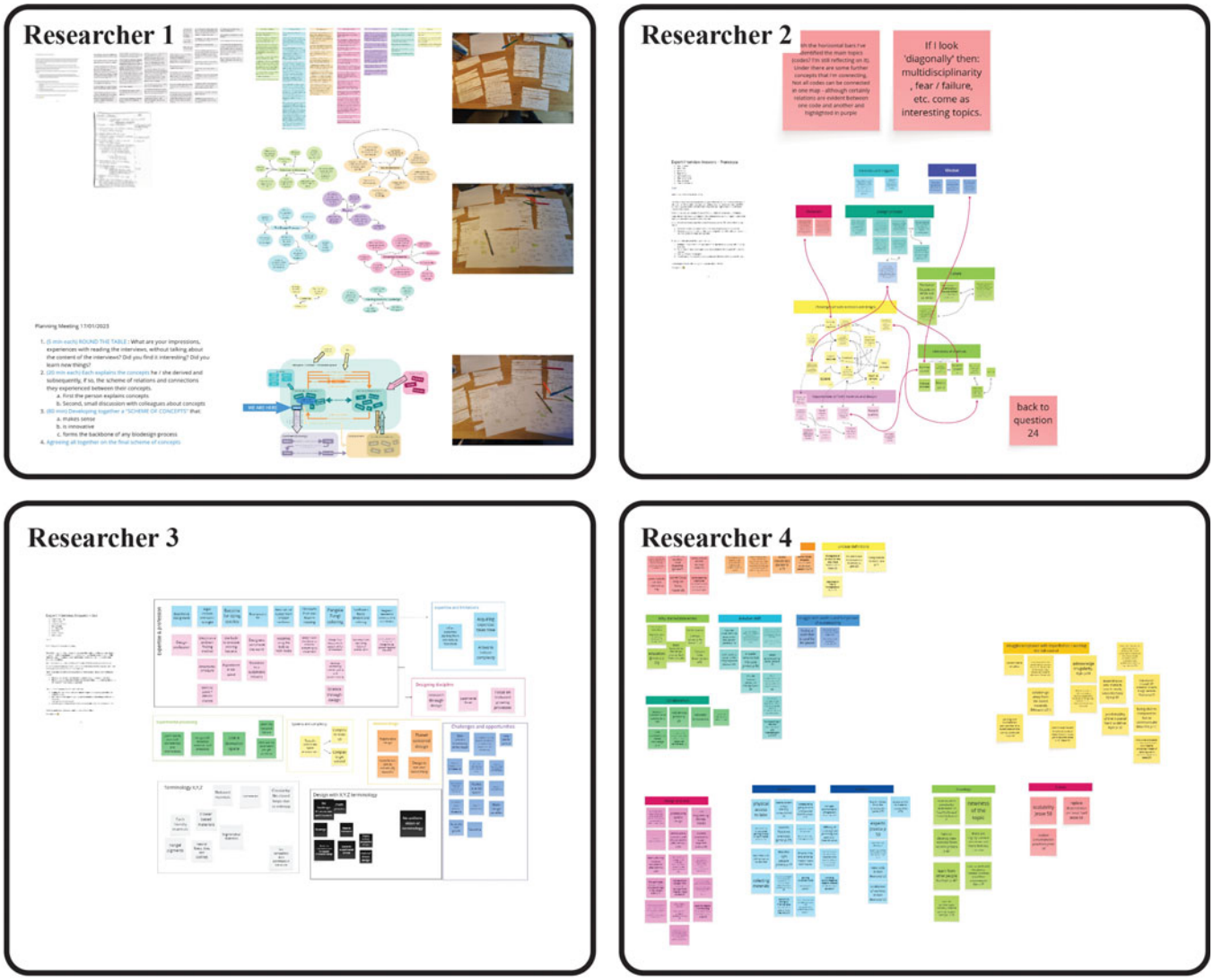


Figure 2. Narrative interview reports as conceptual interview schemes of concepts of the four researchers (access to original file through https://doi.org/10.6084/m9.figshare.26206883).

- What are the challenges and opportunities of biological elements and its accompanying design practice?
- Which obstacles or barriers do you encounter in your design process when designing with biological elements?
- Which advantages or enablers do you identify when designing with biological elements?

From the responses of these three questions, the challenges, obstacles and barriers, as well as the opportunities, advantages and enablers were coded together with interview excerpts for empirical grounding under the overarching codes *Challenges and Opportunities* and *Obstacles/Barriers & Advantages/Enablers*. In this way, this study specifically focused on two of the seven overarching codes. Table 2 holds the subcodes for which each has one or multiple interview excerpts attached to it, ranked from most to least attached excerpts.

Phase 4 – systems thinking

Through the interview excerpts attached to the codes, logical patterns emerged as systemic structures. Accordingly, these codes became either the *stock* or the *flow* elements of the *system of biodesign* which was represented through use of a *Causal Loop Diagram (CLD)* (Forrester 1997; Senge 1990). In systems thinking – especially in its visual representations with CLDs – *stock* are the elements that can be added or subtracted from a system over time, while the *flow* are the actions of processes that increase or decrease (transform) this stock in a system represented by arrows.

The opportunities, advantages and enablers were representing the current *biodesign systemic structures* (= current state of stock and flow), while the challenges, obstacles and barriers were the *hindering systemic structures* (= root causes to advancement of the field). In this way a contemporary system of biodesign was identified with its hindering systemic structures. Some of the systemic structures that emerged, aligned with recognisable *System Archetypes* which describe common patterns in complex systems (Braun 2002). In this way the hindering structures could be explained through these known archetypes and their established Behaviour Over time plotted in a Graph (BOTG) (Braun 2002).

Thus, through *Causal Loop Diagrams* (= containing stock and flow), *System Archetypes* (= recognisable patterns) and *Behaviour Over Time Graphs* (= behavioural cause and effect diagrams

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

Table 2. The subcodes identified for the overarching codes *Challenges and opportunities* and *obstacles/barriers & advantages/enablers* after qualitative analysis of the expert interviews

Challenges and opportunities	Subcodes (Amount of interview excerpts attached to it)
Challenges	Making the desired material properties to be functional (10); Collaboration (9); Knowledge, financial and technological resources (7); Professionalisation today (6); Time consuming (5); No fixed process or methodology (3); Communication (3); Documentation (3); Gaining social acceptance (2); Transparency (2); Cost of materials (1); Specialised equipment (1); Pragmatism (1); Terminology (1)
Opportunities	Sustainable innovation (4); Awareness of waste streams and the biobased movement (2); Practical experience (2); Thinking local (2); Collaboration (2); Scaling up (1); Satisfaction that comes with biodesign projects (1); Inspiration across disciplines (1); Failures (1)
Obstacles/barriers & Advantages/enablers	Subcodes (Amount of interview excerpts attached to it)
Obstacles/barriers	Predictability and control over the material properties (over time) (9); Lacking knowledge, finances and technological resources (6); Collaboration between different fields of study (6); Material development involves a lot of failure (4); Industrialisation as a goal can be experienced as an obstacle (3); Material durability whilst still maintaining the biodegradability (2); Sharing failed experiments with the community (2); Material certification (1)
Advantages/enablers	Collaboration (4); The innovation part (3); Designing of, with and/or for nature (2); Sustainable alternatives (2); Access to knowledge (2); Designing both the material and the product (1); More autonomy and creative freedom (1); Laboratory environment (1); Experimenting (1)

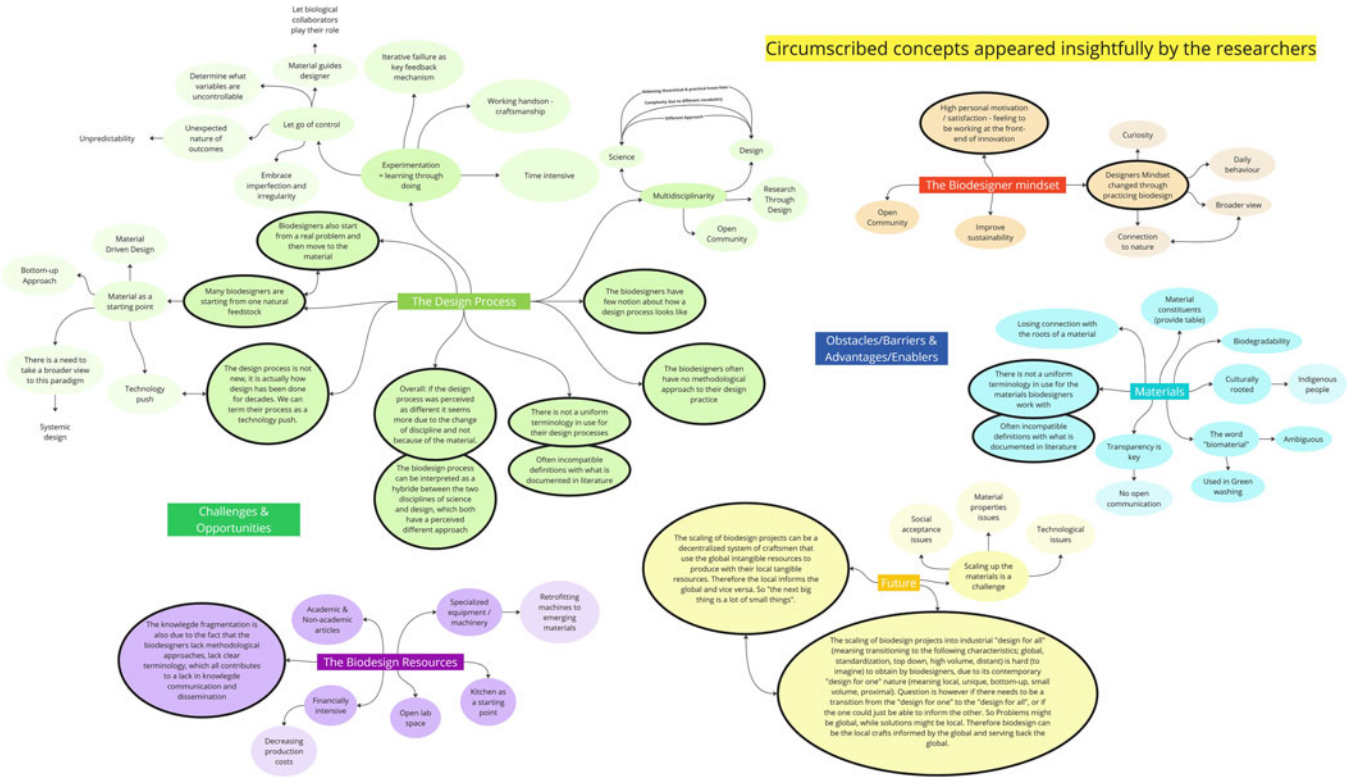


Figure 3. Joint scheme of concepts through consensus building amongst the four researchers, resulting as the preliminary codebook (access to original file through https://doi.org/10.6084/m9.figshare.26206883).

plotted over time) the system of biodesign was identified and analysed to highlight the current systemic structures that might hinder the advancement of biodesign in Industrial Design Engineering Technology contexts (Figure 4).

Validation of these CLDs, BOTGs has happened by two systems thinking expert researchers.

Results

For the advancement of the biodesign field, it is of interest to understand how its design practice is enacted – such as the use of supporting design tools, the integration of different disciplines, the involvement of different design agencies (human and more-than-human) and other enabling conditions.

Systemic understanding of biodesign

As explained in the research method, this understanding is created through a system-oriented research approach. In line with systems thinking, this study explicitly adopts the premise that systems can be described on multiple system depths of which the systemic structures are most fundamental – see Iceberg Model (Kambiz E.

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

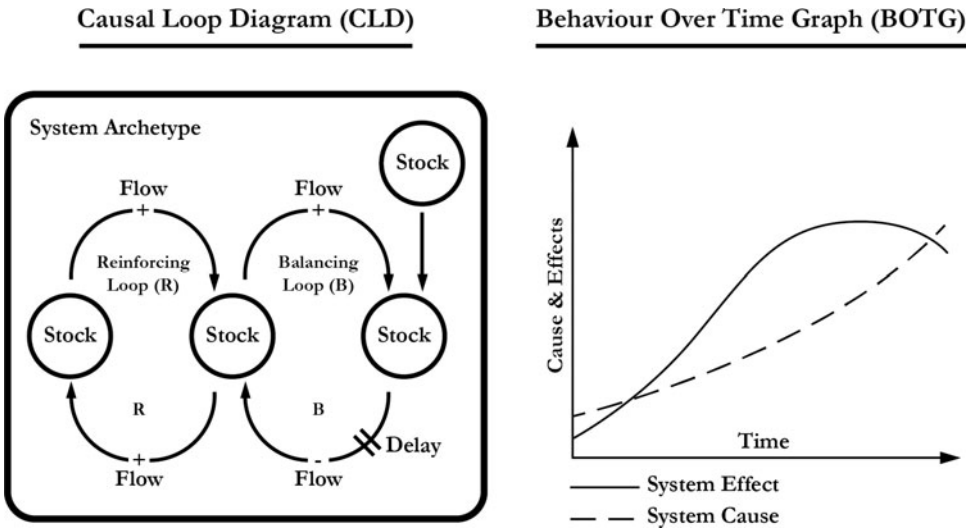


Figure 4. System CLD, Archetype, and BOTG demonstration.

and Cavana 2007; Kim 1992, 1999; Senge 1990). Accordingly, a simplified representation of the system of biodesign is presented in the accompanying Figure 5, which visualises the biodesign system and its diverse system depths as conceptualised in this research.

Within this simplified representation, the designer is positioned centrally at the system depth of (Non-)Human Agency, reflecting how biodesign unfolds through interaction between human agencies and more-than-human agencies. On a deeper system depth, design practicing human agencies are understood to operate through Competency subsystems, which in turn are constructed through underlying subsystems of Knowledge, Skills and Attitudes. Moving to the other deeper side from the agency level, the Design Brief functions as a system depth that informs design agencies of either a design challenge or the opportunity to work with biological elements. Even deeper, the enabling system for the design brief provides Design Tools, which support and operationalise the Design Process system level. Importantly, the system boundaries presented in this study are drawn from a design field enabling perspective, meaning that the system stock & flow acknowledged through evidence-based qualitative analysis – and the system depths identified – are bounded by the perspective of what enables or constrains biodesign.

Systemic structures that hinder advancement of biodesign

The qualitative systemic analysis (as explained in the Methodology) revealed several systemic structures (in Figure 5 represented by black stroked system stock) that might hinder advancement from early curiosity to sustained biodesign advancement. These systemic structures are grounded in the expert interview data through: (1) expert interviews description of concepts database (https://doi.org/10.6084/m9.figshare.26206910) (Vuylsteke *et al.* 2024), (2) figure of the detailed system of biodesign and its empirically grounded evidence of interview excerpts (https://doi.org/10.6084/m9.figshare.31429523) (Vuylsteke *et al.* 2026). Each deeper systemic structure is described in detail and represented in a figure (Figures 6–9) using Causal Loop Diagrams (CLDs), System Archetypes, Behaviour Over Time Graphs (BOTGs) and empirical evidence through interview excerpts that point this out.

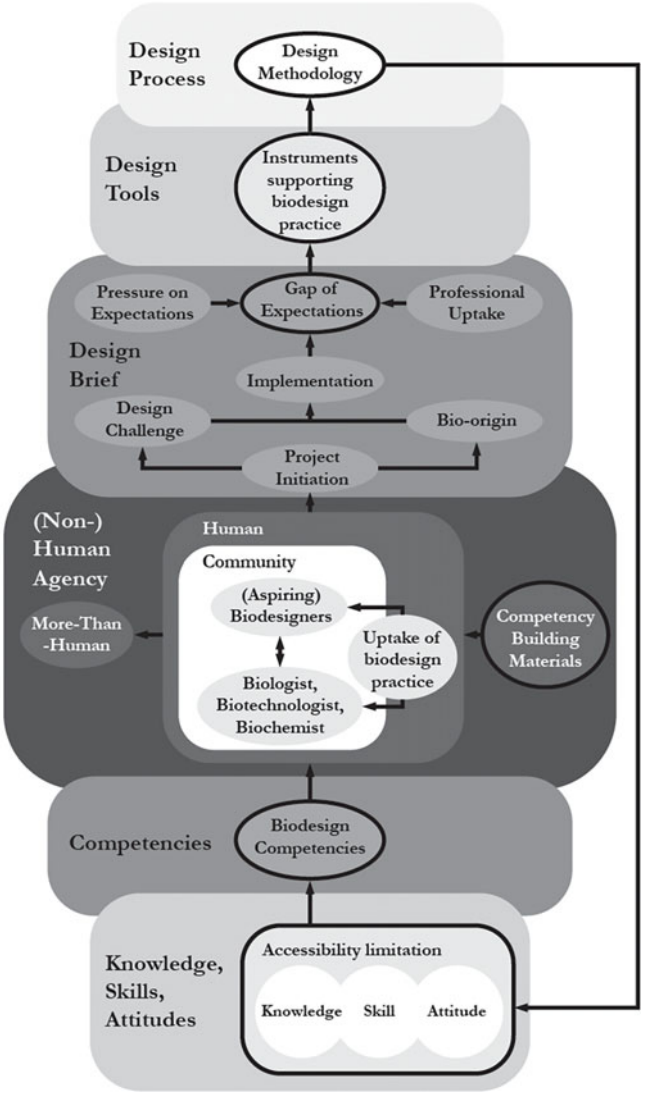


Figure 5. Simplified representation of the system of biodesign (access the detailed system of biodesign through (https://doi.org/10.6084/m9.figshare.31429523).

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

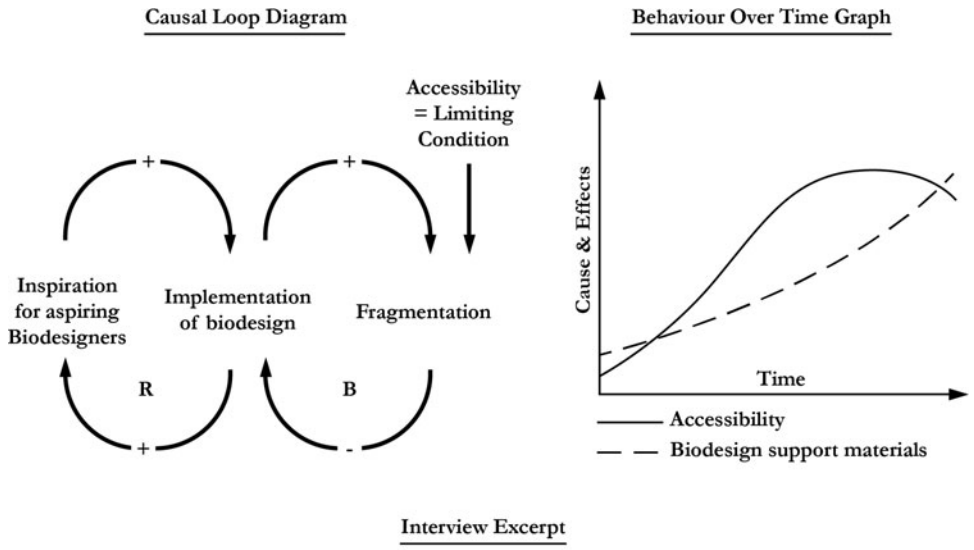


Figure 6. Causal loop diagram, behaviour over time graph and expert interview excerpt of systemic structure 1 – limits to growth – accessibility.

Systemic structure 1 – limits to growth – accessibility

A first systemic structure (Figure 6) can be described as *limits to growth* (Braun 2002). As *knowledge, skills and attitudes* gained from successful demonstrators of biodesign practice increase, demand for a design process and competency building grows as well, reinforcing further growth. However, when diverse design methodologies and knowledge, skills and attitudes are created from many diverse directions without a systemic understanding, these resources increasingly fragment into an unstructured overload of information. This reduces accessibility over time, particularly for starting biodesigners who lack the experience to navigate dispersed, inconsistent or incompatible field supporting materials. Because this fragmentation and reduced accessibility occur at the deepest system depths – *knowledge, skills and attitudes* and *design process* – it becomes a foundational limiting condition that constrains advancement across multiple other systemic levels (Competency, Design Tools, Design Brief, [Non-]human agency). In other words, a weakness experienced at one of the deepest system depths propagates outwards, limiting the capacity of the overall system to reliably build proficiency and advance the biodesign field. As expressed by interviewee A.C. in the below interview excerpt, the experienced fragmentation, the inaccessibility and the insular nature of biodesign related resources today is a limiting condition of aspiring biodesigners to implement this design field in their projects, hence potentially limiting the growth of the overall design field.

Systemic structure 2 – eroding goals – expectations of biodesign projects

A second systemic structure (Figure 7) can be described as *eroding goals* (Braun 2002). There are pressures in the *design brief* to deliver on successful biodesign projects that meet standards, expectations and certification (which are some performance requirements of biodesigned artefacts). Think for example of functionalising desired material properties, matching the product lifespan with the material lifespan, social acceptance or upscaling. These pressures become especially urgent because clients today often demand biodesign outcomes mostly as drop-in replacements that perform as well as pre-existing products. Under these conditions, pressure builds to decrease standards, expectations and certification thresholds for biodesigned solutions, rather than investing on the long-term in foundations (like design methodology or competency building) to meet existing expectations. This dynamic risks normalising reduced ambitions and weakened evaluation criteria over time, thereby undermining the very goals that would otherwise drive the uptake and advancement of biodesign in Industrial Design Engineering Technology. As interviewee J.A. pointed out, it is unrealistic and unjust to the identity of the biodesigned artefact that people demand products which can replace their predecessors on a one-to-one basis (drop-in replacements) and perform just as well; this results in lowering the standards for such biodesigned artefacts. True advancement of the biodesign field therefore requires investing in itself, rather than devaluing biodesign by measuring it against the rigid metrics of the past.

Systemic structure 3 – growth and underinvestment – invest in biodesign competencies

A third systemic structure (Figure 8) can be described as *growth and underinvestment* (Braun 2002). Within the current system, there is underinvestment in *biodesign competency building*, driven by a limiting factor located in the Design Process system depth:

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

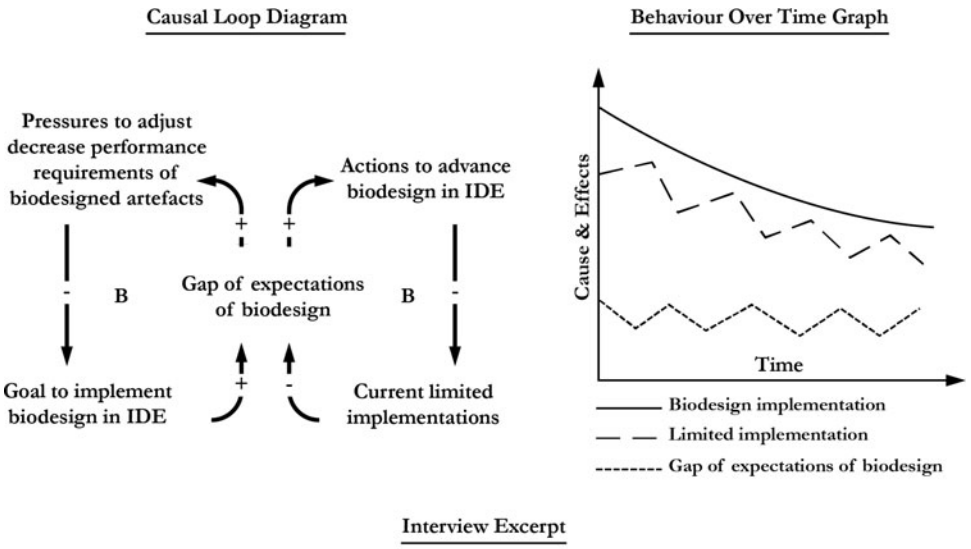


Figure 7. Causal loop diagram, behaviour over time graph and expert interview excerpt of systemic structure 2 – eroding goals – expectations of biodesign projects.

the accessibility to knowledge, skills and attitudes of biodesign (systemic structure 1). This limiting factor contributes to a drift in the Design Brief system depth, where standards, expectations and/or certification requirements for biodesigned artefacts decrease over time (systemic structure 2). The combination of rising interest and insufficient investment in competency building creates a compounding dynamic over time (delayed, see || in the archetype): growth in attention to biodesign does not translate into growth in proficiency and implementation, and the system compensates by adjusting targets downwards rather than strengthening its underlying capacity. As interviewee I.P. noted, rather than compromising on performance, the interviewee refocused on acquiring the biodesign competencies (specific knowledge, skills and attitudes) necessary to navigate and master the field's underlying processes. In this way, this interviewee sought the right working environment that provided it with the resources to enhance its biodesign competencies and reach its desired results.

Systemic structure 4 – tragedy of the commons – knowledge restrictions in biodesign

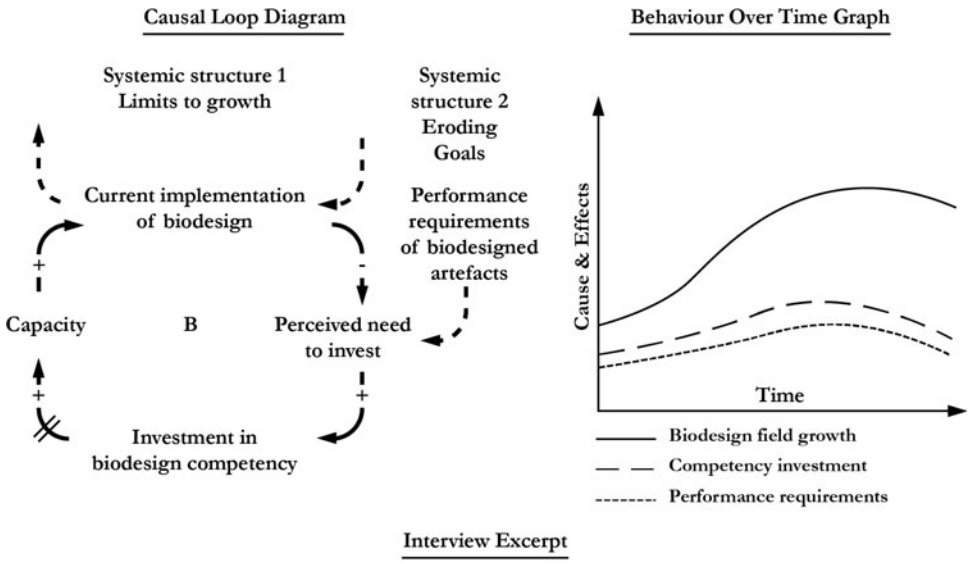
A fourth systemic structure (Figure 9) can be described as a *tragedy of the commons* (Braun 2002). Field support in biodesign are currently fragmented across diverse tools, platforms and formats, often generated by pilot projects and pioneers themselves and are frequently fenced off to protect their knowledge gains and insights, their creations and even their development processes (*agency level*). Thereby limiting reproduction, scaling and the broader uptake of the field – reinforcing the limits-to-growth dynamic (systemic structure 1). At the same time, pioneers' successes inspire new aspiring biodesigners to engage with the field, increasing demand for accessible field support. Yet as long as the commons remains protected and fragmented, further growth is constrained; this may reduce investments and resources and ultimately minimise, limit or even destruct efforts to maintain the commons and long-term investments – here understood as the sustained creation of new design methodologies, competency building, tools, etc. in biodesign. As expressed by interviewee A.C. there is a need for a more organised body of knowledge about biodesign, as currently it seems designers are forced to reverse-engineer finished projects just to understand how they work.

Discussion

Insights

A key insight of this study is the suggestions to move from isolated, well-intentioned biodesign support efforts towards an integrated and complementary support system for biodesign. Rather than treating models, tools, workshops, educational initiatives or platforms and many more as stand-alone solutions, systems thinking may allow to conceptualise biodesign as an interconnected system consisting of multiple system depths, interacting over time. This perspective made it possible to shift the focus from the effectiveness of individual interventions towards the behaviour of the overall systemic structures that hinder the field's advancement. In doing so, the study responds directly to the wicked nature of biodesign, for which no single intervention can suffice and where effectiveness depends on the designers employing it.

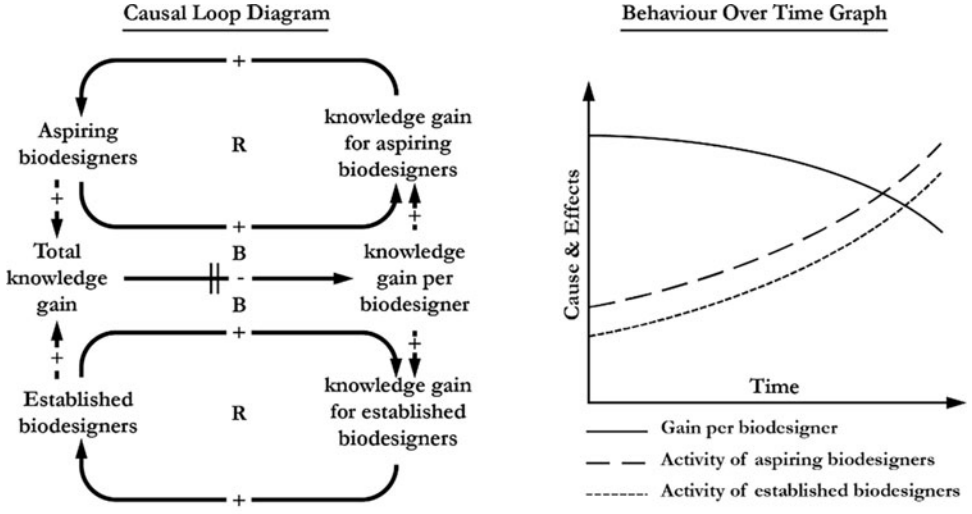
Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.



Interview Excerpt

"I was in the Faculty of Design and I really tried to reach out to scientists and like the Faculty of Science there, but there was no connection whatsoever. And this was really tough for me being a designer, going there and then say like, "hey, I want to turn this fruit into something". So I went to Finland specifically, because they have this collaboration in place. So I was there, started my project doing this and then I was also a teaching assistant for ChemArts for a while. The challenge was definitely that I lack the scientific knowledge, because, working with materials, especially biomaterials, you do need to understand what's inside the material that you're working with. And for me, ChemArts gave me like a basic understanding, but I need it still to look into a lot of scientific papers and try to understand everything myself. And that's definitely challenging." - I.P.

Figure 8. Causal loop diagram, behaviour over time graph and expert interview excerpt of systemic structure 3 – growth and underinvestment – invest in biodesign competencies.



Interview Excerpt

"I'm working on some sort of a primer or what I call a field guide to Biodesign, which is hopefully going to be a written resource to kind of cherry pick concepts in biology and biology related concepts, such as organic chemistry or biotechnology or like the ethics of biodesign. And it's kind of different topics that I think would be useful for someone going into biodesign, not someone who's already established, but I think right now, with all the resources out there are either like recipes or like case studies of like Neri Oxman and all these like famous biodesigners, here's all their work. But like, you kind of have to reverse engineer. Like, how did they get there, you know? And there's no kind of resource on the logistics of it." - A.C.

Figure 9. Causal loop diagram, behaviour over time graph and expert interview excerpt of systemic structure 4 – tragedy of the commons – knowledge restrictions in biodesign.

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

Systemic design of interventions

From this systems-oriented perspective developed in this study, the identified hindering systemic structures can be addressed through two distinct approaches that co-exist.

- One approach is to divide the problem into smaller problems at deeper system depths, for instance by enabling each biodesigner to build their own design processes and competency materials (e.g., journaling progression protocol, IP control, local lab building, etc.). While this may increase local capability, it also risks producing an even more fragmented and scattered system of isolated, localised biodesign initiatives. Therefore a second approach goes in tandem.
- This second approach is to integrate such biodesign supporting tools into a system of interventions at system depths proportional with the size of the actual hindering systemic structure: for example, a field enabling system with tools that provide methodological guidance and empowers existing and aspiring biodesigners to take up biodesign principles within their Industrial Design Engineering Technology projects.

Given these two approaches, interventions can be designed which divide the wicked problem into smaller ones, but at the same time integrate the proposed solutions in an overarching, adaptive structure that is proportionate to the biodesign system it addresses (Kauffman Jr. 1980). Some promising potential interventions that may support advancement of biodesign across its multiple system depths are here proposed, but it is suggested that future research must not be limited to these alone:

- Systemic Structure 1 – Limits to growth – Accessibility: Located on the deepest system depth and propagating through all other depths, is the accessibility to knowledge and competency building. Therefore, a methodological structuring of the design process, combined with a reference point for competency building in biodesign hold promising potential to advance the field. This has also been acknowledged by the open call in Research Directions: Biotechnology Design, where leading scholars asked "How do we grow a biodesigner?" – inviting contributions to define the field's education and practice (Vijayakumar *et al.* 2024). By mapping how pioneering biodesigners articulated and structured their practices – as acknowledged by peer researchers, that is, Jang *et al.*, this study and future work may better understand the leverage points at which to potentially meaningfully intervene (Jang *et al.* 2024).
- Systemic Structure 2 – Eroding goals – Expectations of biodesign projects: This archetype described how the increasing pressure to rapidly deliver high-performance, drop-in replacements using biological elements can lead to a lowering of standards and expectations of biodesign projects. Instead of investing in the long-term development required for successful biodesign, practitioners may resort to superficial, symptomatic solutions. To counter this tendency, the proposed methodological structuring of the design process can be translated into a series of practically applicable and accessible interventions. These interventions may for example include a guiding card set that informs, inspires and/or activates users or a digital platform with inspiring examples that also hosts other essential biodesign related information, etc. Most importantly, while such interventions would operate individually at the system depth of tools, their collective integration may potentially form a toolkit, which functions at the system depth of design brief. Such toolkit may therefore enable designers to formulate new biodesign opportunities and challenges to be solved, explore biological elements and structure their design processes more effectively. Respectively, scholars indirectly noted that such system of interventions (toolkit) may support an ongoing transition from fragmented initiatives of biodesign (Bandoni *et al.* 2022; Chen *et al.* 2023; Gough *et al.* 2021b) towards a more coherent conceptual consolidation (Dade-Robertson and Zhang 2024).
- Systemic Structure 3 – Growth and underinvestment – Invest in biodesign competencies: When increasing interest in biodesign does not translate into sustained investment in competency building. As a consequence of the previously described limits to growth and eroding goals, expectations and performance standards may gradually decline. To address this systemic structure, the previously introduced competency reference point for biodesign may help. This may even serve a dual purpose. On the one hand, it provides guidance for the development of future educational programmes that aim to train biodesign practitioners. On the other hand, it functions as a reflective tool that allows companies and designers to assess their own progression in biodesign competency development. Today already, a growing number of institutions are incorporating biodesign into various design-related curricula, which demonstrates a growing interest in competency building in this field of design (Strobel do Nascimento and Heemann 2023).
- Systemic Structure 4 – Tragedy of the commons – Knowledge restrictions in biodesign: The tendency of pioneers to gatekeep intellectual gains for competitive advantage presents a barrier to the advancement of biodesign. This behaviour, while understandable, restricts the shared methodologies essential for innovation. Mitigating this requires a dual approach: the deployment of knowledge-dissemination events – such as seminars or workshops – and the adoption of open-science and open-source practices to facilitate the common field knowledge. To date, broader perspectives in design and innovation research therefore emphasise that complex practices are not solely shaped by individual initiatives, but also by the infrastructures and ecosystems within which they are embedded (Ihls and Pollini 2025).

Limitations

Six limitations of this study are here listed. (1) The selected experts – however representing all intended target audiences - may still not fully represent the current scope of biodesign professionals (i.e. excluding people of the life-sciences). (2) Interviews were in English, which was not the native language for most participants, possibly limiting the depth of discussion. (3) While four researchers conducted the qualitative analysis, the final coding was done by only one researcher. (4) the systemic representation - including the system depths, stock & flow - is purely constructed through the viewpoint of biodesign. (5) The systemic structures hindering the advancement of biodesign, expressed as archetypes that are empirically grounded through the expert interview data, may still not capture all patterns. (6) The CLDs and BOTGs have only been validated by two systems thinking experts.

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

Conclusion

This study set out to address the research question: "What systemic structures hinder advancement of biodesign?." Drawing on extensive interviews with 21 pioneering biodesign experts ($n = 21$) and qualitatively analysing their experiences through a systems-oriented perspective, the study demonstrates that the limited uptake of biodesign within Industrial Design Engineering Technology cannot be reduced to isolated practical barriers. Rather, it is rooted in deeper systemic structures that unfold across multiple nested system depths – from knowledge, skills and attitudes, to competencies, (non-)human agency, design briefs, tools and processes.

Four recurring system archetypes were identified as particularly constraining. (1) First, a limits-to-growth systemic structure reveals how fragmentation of methodologies and competency-building reduces accessibility, particularly for emerging practitioners. When foundational knowledge structures are dispersed and unaligned, progression across deeper system levels is restricted. (2) Second, an eroding-goals systemic structure highlights how pressures to meet conventional performance standards, certification schemes and market expectations can gradually lower ambitions for biodesign projects, normalising compromised objectives instead of strengthening underlying biodesign capacities. (3) Third, a growth-and-underinvestment systemic structure shows how increasing attention to biodesign is not matched by proportional investment in competency development, resulting in rising interest without corresponding growth in proficiency. (4) Final and fourth, a tragedy-of-the-commons systemic structure exposes how fragmented and often protected practice-support tools limit collective learning, scaling and consolidation of the field, despite growing demand for shared infrastructures.

Together, these systemic structures reveal that the obstruction of biodesign is not primarily a matter of individual resistance or technical infeasibility, but of systemic nature. Biodesign currently operates within a support system that remains fragmented, unevenly resourced and structurally underdeveloped. The field's complexity – shaped by multi-species agency, transdisciplinary collaboration, ethical considerations and heightened variability – demands more than isolated interventions. It requires coordinated systemic design of practice-enabling infrastructures, that is, methodological process structuring, competency reference points, applicable supportive tools, etc.

A key contribution of this study is therefore methodological: by applying systems thinking to the biodesign field, it shifts the discussion from evaluating individual tools or initiatives towards understanding the behaviour of the overall system. This perspective makes visible reinforcing and balancing feedback loops, delays and unintended consequences that would otherwise remain obscured. In doing so, it responds directly to the wicked and systemic nature of biodesign implementation in Industrial Design Engineering Technology.

Two broad strategic directions emerge. One is to decentralise and localise solutions, enabling individual practitioners to construct their own competency trajectories and processes. While this may strengthen local capacity, it risks further fragmentation. The alternative that must co-exist with the first approach is to intervene at deeper system depths through the development of integrated, practice-enabling systems that align methodologies, competency-building, tools and evaluation criteria. Such systemic interventions are more proportionate to the scale of the identified systemic structures and more likely to generate cumulative, long-term impact.

Data availability statement. The data that support the findings of this study are openly available in Figshare at:

- https://doi.org/10.6084/m9.figshare.26206817, (Vuylsteke *et al.* 2022a).
- https://doi.org/10.6084/m9.figshare.26206883, (Vuylsteke *et al.* 2022b).
- https://doi.org/10.6084/m9.figshare.26206910, (Vuylsteke *et al.* 2024).
- https://doi.org/10.6084/m9.figshare.31429523, (Vuylsteke *et al.* 2026).

Acknowledgements. We are grateful for the professional biodesign practitioners who have participated in this study and for sharing their invaluable insights.

Author contributions. Conceptualisation: Bert Vuylsteke; Francesca Ostuzzi, Jan Detand. Methodology: Bert Vuylsteke. Data curation: Bert Vuylsteke. Data visualisation: Bert Vuylsteke. Writing original draft: Bert Vuylsteke. All authors approved the final submitted draft.

Financial support. This research was supported by grants from the Interreg North Sea Region Building Based on Bio-Based project under Grant Call 3C (FA); and Vlaio Circular Living Lab Hemp+ project under Grant VNS.2022.0142.

Competing interests. None.

Ethical standards. This research was conducted in accordance with the principles embodied in the Declaration of Helsinki and in accordance with local statutory requirements. Written informed consent has been collected from all participating designers. All participants approved for their results and abbreviated names to be included in this article. The Chair of the University Faculty's Ethics Review Committee informed that, in compliance with the general ethics protocol, this research was conducted under the conditions of the Faculty's ethics waiver programme and is therefore not subject to mandatory additional review by the Ethics Review Committee.

References

Abram D (1996) *The Spell of the Sensuous: Perception and Language in a More-Than-Human World*. Vintage Books.

Albrecht G and Van Horn G (2016) Exiting the anthropocene and entering the symbiocene. *Minding Nature* **9**(2), 12–16.

Antonelli P (2018) Vital design. In *Biodesign: Nature, Science, Creativity*. Thames & Hudson Ltd, pp. 6–7.

Armstrong R (2022) Biodesign for a culture of life: Of microbes, ethics, and design. In Proceedings of DRS, Vol. 2022. 0–20. Available at https://doi.org/10.21606/drs.2022.144.

Ashby WR (1956) An Introduction to Cybernetics. *Physics Today* **10**(7), 34–36.

Bandoni A, Almendra R and Forman G (2022) Interdisciplinarity and collaboration - a study focusing on experienced biodesign practitioners. In *Human Dynamics and Design for the Development of Contemporary Societies* 25(January). https://doi.org/10.54941/ahfe1001374.

Birch E, Bridgens B, Zhang M and Dade-Robertson M (2024) Biological, physical and morphological factors for the programming of a novel microbial hygromorphic material. *Bioinspiration and Biomimetics* **19**(3). https://doi.org/10.1088/1748-3190/ad3a4d.

Braun W (2002) The system archetypes. 27. Available at http://www.albany.edu/faculty/gpr/PAD724/724WebArticles/sys_archetypes.pdf

Camere S and Karana E (2018) Fabricating materials from living organisms: An emerging design practice. *Journal of Cleaner Production* **186**, 570–584. https://doi.org/10.1016/j.jclepro.2018.03.081.

Ceschin F and Gaziulusoy I (2016) Evolution of design for sustainability: From product design to design for system innovations and transitions. *Design Studies* **47**, 118–163. https://doi.org/10.1016/j.destud.2016.09.002.

Chen L, Cai Z, Jiang Z, Long Q, Sun L, Childs P and Zuo H (2023) A knowledge-based ideation approach for bio-inspired. *Proceedings of the Design Society* **3**(JULY), 231–240. https://doi.org/10.1017/pds.2023.24.

Cole RJ (2012) Transitioning from green to regenerative design. *Building Research & Information* **40**(1), 39–53. https://doi.org/10.1080/09613218.2011.610608.

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

Cotsaftis O, Williams N, Chyon G, Sadar J, Va Pesaran DM, Wines S and Naarden S (2023) Designing conditions for coexistence. *Design Studies* **87**, 101199. https://doi.org/10.1016/j.destud.2023.101199.

Crutzen PJ (2002) Geology of mankind. *Nature* **415**(23). https://doi.org/10.1038/415023a.

Crutzen PJ (2022) The 'Anthropocene' (2000). In *Paul J. Crutzen and the Anthropocene: A New Epoch in Earth's History*. Springer International Publishing, pp. 19–21.

Dade-Robertson M and Zhang M (2024) Theory and design in the biotechnical age: A schematic understanding of bio design and synthetic biology practice. *The Design Journal* **27**(5), 800–822. https://doi.org/10.1080/14606925.2024.2381914.

Dierckx de Casterle B, Gastmans C, Bryon E and Denier Y (2012) QUAGOL: A guide for qualitative data analysis. *International Journal of Nursing Studies* **49**(3), 360–371. https://doi.org/10.1016/j.ijnurstu.2011.09.012.

du Plessis C (2012) Towards a regenerative paradigm for the built environment. *Building Research & Information* **40**(1), 7–22. https://doi.org/10.1080/09613218.2012.628548.

Dubberly H and Pangaro P (2015) Cybernetics and design: Conversations for action. *Cybernetics & Human Knowing* **22**(3), 73–82.

Dubberly H and Pangaro P (2023) How might we help designers understand systems? *She Ji* **9**(2), 135–156. https://doi.org/10.1016/j.sheji.2023.05.003.

Dumon L and Ostuzzi F (2021) Relate systems archetypes and collaboration A case study in the context of DIY bio-based materials in design education. In Proceedings of Relating Systems Thinking and Design (RSD10) 2021 Symposium. Available at https://rsdsymposium.org/relate-systems-archetypes-and-collaboration-a-case-study-in-the-context-of-diy-bio-based-materials-in-design-education/

Forrester JW (1997) Industrial dynamics. *Journal of the Operational Research Society* **48**(10), 1037–1041.

Gibson JJ (1977) The theory of affordances. In *The People, Place, and Space Reader*. Routlegde, pp. 56–60.

Ginsberg AD and Chieza N (2018) Editorial: Other biological futures. *Journal of Design and Science*. https://doi.org/10.21428/566868b5.

Gough P, Forman J, Pataranutaporn P, Hepburn LA, Ramirez-Figueroa C, Cooper C, Vujic A, Kong DS, Kim R, Maes P, Ishii H, Sra M and Ahmadpour N (2021a) Speculating on Biodesign in the Future Home. Conference on Human Factors in Computing Systems – Proceedings, pp. 11–15. https://doi.org/10.1145/3411763.3441353.

Gough P, Pschetz L, Ahmadpour N, Hepburn L-A, Cooper C, Ramirez-Figueroa C and Catts O (2020) The Nature of Biodesigned Systems. In Companion Publication of the 2020 ACM Designing Interactive Systems Conference. New York, NY, USA: ACM, pp. 389–392. https://doi.org/10.1145/3393914.3395908.

Gough P, Yoo S, Tomitsch M and Ahmadpour N (2021b) Applying bio-affordances through an inquiry-based model: A literature review of interactive biodesign. *International Journal of Human-Computer Interaction* **37**(17), 1583–1597. https://doi.org/10.1080/10447318.2021.1898846.

Ihls J and Pollini B (2025) From observation to operation: The role of lab spaces in biodesign practice. *Biotechnology Design* **4**(e2). https://doi.org/10.1017/S2977905725100012.

Jang SY, Kwon JH, Song H and Choi SY (2024) A study on the changes and scalability of bio-design: Focusing on changes in the last five years. *Korea Institute of Design Research Society* **9**(3), 276–293. https://doi.org/10.46248/kidrs.2024.3.276.

Kääriäinen P, Tervinen L, Vuorinen T and Riutta N (2020) *The CHEMarts Cookbook*, 2nd Edn. Aalto: Aalto University.

Kambiz E M and Cavana RY (2007) *Systems Thinking, System Dynamics: Managing Change and Complexity*. Pearson Prentice Hall.

Karana E, McQuillan H, Rognoli V and Giaccardi E (2023) Living artefacts for regenerative ecologies. *Research Directions: Biotechnology Design* **1**(1), e16. https://doi.org/10.1017/btd.2023.10.

Kauffman Jr. DL (1980) Systems one: An introduction to systems thinking. The Innovative Learning Series. 41.

Kim DH (1992) *Systems Archetypes II: Using Systems Archetypes to Take Effective Action, Vol. 2*. Waltham: MA: Pegasus Communications.

Kim DH (1999) Introduction to systems thinking. In MA: Pegasus Communications, Vol. 16. Waltham.

Kim R (2021) Virus as Quasi-Living Bio-Material for Interaction Design: Practical, Ethical, and Philosophical Implications. In Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems. New York, NY, USA: ACM, pp. 1–7. https://doi.org/10.1145/3411763.3451770.

Kopnina H (2017) Commodification of natural resources and forest ecosystem services: Examining implications for forest protection. *Environmental Conservation* **44**(1), 24–33. https://doi.org/10.1017/S0376892916000436.

Lee S, Congdon A, Parker G and Borst C (2020) Understanding 'Bio' Material Innovations: A Primer for the Fashion Industry BioFabricate & Fashion for Good. Available at https://reports.fashionforgood.com/wp-content/uploads/2020/12/Understanding-Bio-Material-Innovations-Report.pdf%0A https://app.box.com/s/amjq9anszv8hvwdexoxg6wubes4aaxqa

Lumivero (2022) NVivo QDA software.

McMahon M and Hadfield M (2007) The butterfly effect: Creative sustainable design solutions through systems thinking. FAIM: Intelligent Manufacturing Now. Available at http://eprints.bournemouth.ac.uk/9727/1/FAIM2006_McM-244.pdf

Myers W (2018a) Beyond biomimicry. In *Biodesign: Nature, Science, Creativity*. pp. 10–17.

Myers W (2018b) *Biodesign: Nature, Science, Creativity*. Thames & Hudson Ltd.

Myers W (2018c) The hybrid frontier. In *Biodesign: Nature, Science, Creativity*. Thames & Hudson Ltd, pp. 8–9.

Nelson HG and Stolterman E (2014) *The Design Way: Intentional Change in an Unpredictable World*, 2nd Edn. Cambridge: MIT Press.

Norman DA (1988) *The Psychology of Everyday Things*. Basic books.

Ostuzzi F (2017) *Open-Ended Design. Explorative Studies on How to Intentionally Support Change by Designing with Imperfection*.

Oxman N (2016) Age of entanglement. *Journal of Design and Science*. https://doi.org/10.21428/7e0583ad.

Pataranutaporn P, Vujic A, Kong DS, Maes P and Sra M (2020) Living Bits. In Proceedings of the Augmented Humans International Conference. New York, NY, USA: ACM, pp. 1–12. https://doi.org/10.1145/3384657.3384783.

Pollini B and Rognoli V (2024) Healing materialities: Framing biodesign's potential for conventional and regenerative sustainability. *Research Directions: Biotechnology Design* **2**, 21. https://doi.org/10.1017/btd.2024.14.

Senge P (1990) *The Art and Practice of the Learning Organization. Vol.1*. New York: New York: Doubleday.

Shiva V (2000) *Tomorrow's Biodiversity*, 1st Edn. London, UK: Thames & Hudson Ltd. https://catalogue.nla.gov.au/catalog/2245892

Stevens LL, Fehler M, Bidwell D, Singhal A and Baumeister D (2022) Building from the bottom up: A closer look into the teaching and learning of life's principles in biomimicry design thinking courses. *Biomimetics* **7**(1). https://doi.org/10.3390/biomimetics7010025.

Strobel do Nascimento E and Heemann A (2023) How to teach interspecies design? Formal education in biodesign ensino formal em biodesign. In *ENSUS2023 - XI Encontro de Sustentabilidade em Projeto*. https://doi.org/10.29183/2596-237x.ensus2023.v11.n3.p194-204.

Thomsen MR and Tamke M (2022) Towards a transformational eco-metabolistic bio-based design framework in architecture. *Bioinspiration & Biomimetics* **17**(4), 045005. https://doi.org/10.1088/1748-3190/ac62e2.

Välk S, Chen Y, Dieckmann E and Mougenot C (2023) Supporting collaborative biodesign ideation with contextualised knowledge from bioscience. *CoDesign* **19**(2), 142–161. https://doi.org/10.1080/15710882.2022.2138447.

Vandenbroeck P (2012) Working with wicked problems. King Baudouin Foundation. Brussels, 1–50.

Vijayakumar V, Cogdell C, Correa I, Dade-Robertson M, Danies G, Edens S, Forlano L, George J, Grushkin D, Holbert N, Hoover R, Jalkh H, Kisielewski A, Obregon C, Pirone J, Polli A, Scarpelli A, Stukes S, Ward D, Wintermute J, Balangue M and Walker J (2024) How do we grow a biodesigner? *Research Directions: Biotechnology Design* **2**, e2. https://doi.org/10.1017/btd.2024.1.

Vuylsteke B, Detand J and Ostuzzi F (2023) Exploring the intersection of Design and Biology in today's industry. In IOP Conference Series: Earth and

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.

Environmental Science, Vol. 1256. Bandung, Indonesia, 012004. https://doi.org/10.1088/1755-1315/1256/1/012004.

Vuylsteke B, Ostuzzi F and Detand J (2022a) Expert Interview Protocol. Figshare. Available at https://doi.org/10.6084/m9.figshare.26206817.

Vuylsteke B, Ostuzzi F and Detand J (2022b) Expert Interview Scheme of Concepts - Preliminary Codes. Figshare. Available at https://doi.org/10.6084/m9.figshare.26206883.

Vuylsteke B, Ostuzzi F and Detand J (2026) System of biodesign practice. Figshare. Available at https://doi.org/10.6084/m9.figshare.31429523.

Vuylsteke B, Ostuzzi F, Detand J and Dumon L (2024) Expert Interview Description of Concepts. Figshare. Available at https://doi.org/10.6084/m9.figshare.26206910.

Wakkary R (2021) *Things We Could Design: For More than Human-Centered Worlds*. MIT Press.

Wiek A, Withycombe L and Redman CL (2011) Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science* **6**(2), 203–218. https://doi.org/10.1007/s11625-011-0132-6.

Downloaded from https://www.cambridge.org/core. 15 Nov 2026 at 01:05:29, subject to the Cambridge Core terms of use.