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Corresponding authors: Julia Ihls;
Email: jihls@hfg-karlsruhe.de, Barbara Pollini;
Email: barbara.pollini@aalto.fi

*These two authors contributed equally to this work.

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From observation to operation: the role of lab spaces in biodesign practice

Julia Ihls[1,2,*] and Barbara Pollini[3,*]

[1]University of Arts and Design, Karlsruhe, Germany; [2]Architecture and Design Department, Technical University Munich, School of Engineering and Design, Munich, Germany and [3]Design Department, School of Arts, Design and Architecture, Aalto University, Espoo, Finland

Abstract

Biodesign is an emerging field integrating design and science; its rise necessitates a reassessment of educational paths and working spaces for cross-disciplinary explorations, such as working with living materials and adhering to safety standards. The article examines laboratory environments dedicated to biodesign practice and education, varying from low-tech to high-tech setups and from university to community spaces, aiming to clarify the role of workspaces and infrastructures in supporting transdisciplinary research between design and science.

We surveyed Biodesign Laboratories worldwide, addressing the current status quo of various lab configurations and their unique spatial typologies to accommodate biodesign's hybrid nature.

The result is an overview of the socio-technical topos of the laboratory as a literal breeding ground for (future) biodesigners. The qualitative data reported in this article aim to enhance the understanding of Biodesign Labs by analysing the potential of various laboratory configurations to accommodate biodesign's hybrid nature, potentially developing unique spatial typologies.

The lab as an evolving infrastructure

When discussing interdisciplinary and even transdisciplinary work in biodesign, the question arises about the epistemic spaces that enable such engagement. As discourses on the non-human turn or new materialism show, the Western form of knowledge production – reflected in institutional infrastructures such as methods, tools or work environments – is increasingly reaching its limits (Haraway, 2016). It is therefore not surprising that current theories question standard methods and (infra-)structures, and address the need for explorative practices, post-qualitative research or situated knowledge (Thomas and Bellingham, 2020; Tsing, 2017). Ultimately, it seems only consistent that – if we engage with "more-than-human" or post-humanist narratives (Braidotti, 2019; Grusin, 2015) – a (self-) critical reflection must also take place at the spatial-infrastructural level of the biodesign discipline. The hybrid nature of biodesign, as a fluid and relatively young design sub-discipline, oscillates between partly related, partly very heterogeneous knowledge domains such as (micro)biology, life sciences, material sciences, speculative design, fashion and product design or architecture. These fields have their own infrastructural and spatial requirements, be it wet labs, dry labs, cleanrooms or workshops and multi-purpose rooms. In this diverse and sometimes contradictory landscape, biodesign often causes friction: standard lab infrastructures may not accommodate slower biological growth processes and creative work with living materials may be constrained by safety regulations and institutional hierarchies. At the same time, design practices often require open-ended experimentation and intuitive approaches that can conflict with protocol-heavy scientific workflows. Given this interdisciplinary mix, the question arises about the spatial needs of biodesign practice. What are the characteristics of a lab in which design and science interact equally? Which tools are essential for interdisciplinary work? How fluid and modular must the spatial arrangement be, and how high-tech or low-tech is the equipment?

The article aims to enhance understanding of the role of biodesign spaces by analysing different laboratory environments. It provides an overview of the current status quo of various Biodesign Labs and explores the potential of various spatial configurations to accommodate biodesign's hybrid nature, potentially developing unique spatial typologies. To this end, the historical developments of the laboratory as a spatial topos and the biodesign discipline are contextualised at the beginning. Drawing on a qualitative survey, we then map the socio-technical role of labs in supporting biodesign and the next generation of hybrid practitioners. We identify three emerging spatial typologies – scientific-analytical, biotinkering-explorative, and balanced all-rounder – that reflect the varied ways in which infrastructure shapes, supports and constraints biodesign practice today. In doing so, we argue that lab spaces are not merely containers for knowledge production but active participants in shaping biodesign's epistemic and material cultures.

History of the lab

What do we actually mean by a "laboratory" to begin with – a concept that certainly does not operate in a vacuum, but is part of an architectural history as a distinctly spatial topos? The first precursors of the laboratory can be identified as early as the 17th and 18th centuries as epitomes of research, production and instruction. Thus, heterogeneous experimental spaces can already be found in private castle complexes and alchemical kitchens, which, however, are characterised mainly by small-scale isolation and were created through personal initiatives (Straub and Landbrecht, 2016). This changed with the so-called "laboratory revolution" in the late 19th and early 20th century, analogous to the differentiation of the natural sciences and universities. During this increasing institutionalisation, the natural science lab became an iconographic topos of a sterile place for scientific research – flanked by instruments of laboratory epistemology: the microscope, white coat and test tubes (Straub, 2016). This spatial arrangement is characterised by a high degree of generic standardisation and placelessness and still shapes the common association of laboratories today. Subsequently, the concept of the laboratory underwent a further transformation in the second half of the 20th century; with the emergence of increasingly state and third-party funded research funding models and the technological shift towards computer-based work, an increasingly entrepreneurial ethos shaped their design and architecture (Klonk, 2016). Global collaborations and interdisciplinarity became increasingly relevant, which was reflected in their corresponding promotion. As a result, modular, adaptive and transparent structures became relevant for lab designs, enabling a fluid transition between laboratory and public space, between interior and exterior – glass walls or furniture on wheels, as can be found in iconic examples of laboratory architecture such as the James H. Clark Center for Biomedical Engineering and Sciences at Stanford University or the MIT Media Lab (Landbrecht, 2016). This flexible open lab typology largely replaced the closed laboratory at the end of the 1990s, which not only reinforced the blurring of interdisciplinary professional boundaries but also increasingly softened the spatial transitions to related working environments such as the workshop, the studio-atelier or the museum (Watch, 2001; Hansmann, 2016). Importantly, the lab is not a neutral container for knowledge production but a socio-technical actor. Science and Technology Studies (STS) has long emphasised how spatial infrastructures co-produce scientific knowledge and practice (Latour and Woolgar, 1986; Knorr-Cetina, 1981). This also applies to biodesign, where the interplay between material constraints, institutional cultures and epistemic ambitions is especially dynamic. Given biodesign's hybrid and emerging status, the question arises: why choose the concept of the "lab" at all? Couldn't biodesign equally unfold in kitchens, studios or greenhouses? While these alternative spaces are indeed part of biodesign's genealogy – especially within DIYbio and feminist technoscience movements – the lab remains a productive conceptual frame that foregrounds questions of protocol, safety, legitimacy and access. Therefore, the lab has become a cultural code – a site where authority, discipline and scientific aesthetics are negotiated and sometimes subverted (Kelley, 2016). To outline this more concretely, it is first necessary to sharpen the concept of biodesign and its current characteristics.

Defining lab settings and practices

Biodesign emerged as a bottom-up phenomenon supported by DIY culture over a decade ago (Antonelli, 2008; Myers, 2012); only recently, it began to be integrated as a discipline in design academies and universities. As a result, the spaces to practise and teach this emerging discipline can vary significantly in appearance, structure and equipment. The standard these spaces aim for is that of scientific laboratories, consequently reinterpreted and readjusted according to creative needs and facility possibilities. Where biodesign should be performed and taught and what equipment and infrastructural characteristics require this practice are still open questions (Vijayakumar et al., 2024; Naito and Botero, 2024). The young age of the discipline, the fact that it can be performed in low-tech and high-tech environments, and the constraints given by the involvement of living organisms make this answer not straightforward.

Biodesign is still a challenging field to enter (Crawford, 2023; Naito and Botero, 2024). The growing biodesign community, thriving from domestic to design studio spaces, might rely on the ingenuity and resourcefulness of the practitioners, sometimes limiting the types of exploration and organisms involved. These limits push the designers to look for access to the proper tools, workspaces and scientific community feedback (Crawford, 2023). Community biomakerspaces were among the first established spaces for biodesign research and creative practice on a community level, supporting (semi-)professional individuals facing challenges locating the necessary lab space and equipment (Seyfried et al., 2014). Community laboratories have been defined as "informal learning environments that provide access to the resources necessary to carry out pursuits using enabling biotechnologies" (Walker et al., 2023); these still emerging spaces are vibrant hubs, actively fostering informal citizen engagement in life science learning and experimentation (ibid.).

Over the past decade, biodesign received increasing attention as a groundbreaking approach capable of providing sustainable solutions at the material and product levels while also encouraging critical thinking about the human-nature relationship and interconnectedness (Pollini and Rognoli, 2024). This approach is implemented from primary schools to the university level to expand design and life science education horizons, promoting transdisciplinarity and critical thinking about technology production and society (Walker et al., 2023a; Ihls and Oestreicher, 2023). Design universities are starting to integrate biodesign into their study programmes, offering suitable lab spaces for collaboration between design and sciences, and providing design students with training courses, necessary equipment, clean workspaces and protocols.[1] Depending on the type of activity carried out, biodesign may require more or less equipped and sterile spaces; the same can be said for the necessary tools and machinery. Primary and early biodesign experiments, such as growing and working with bacterial cellulose or mycelium, can also be carried out in low-tech laboratories for simple material growing and processing exercises. In contrast, other activities, such as synthetic biology, might require more high-tech instruments and spaces that are not easily implementable in the facilities of a design university. For some designers and researchers in the field, joining an already established scientific lab has also been an option (Stefanova, 2021; Pollini, 2024; Sawa, 2016), thus reinforcing the definition of the "designer in lab," namely designers who spend a significant amount of their working time in a scientific lab (Langella, 2019; Sawa, 2016). Such transdisciplinary collaborations among departments and institutions allow the designer to benefit from a work environment rich in scientific feedback and insights, enabling more sophisticated experiments and material processing thanks to high-tech equipment. This variety of options defines different spaces, with various purposes and biodesign possibilities depending on their settings (Pollini, 2024). High-tech and scientific labs may either not be necessary for some basic activities or not be accessible (for geographical or economic reasons or lack of cross-collaboration between departments and institutions). Divergent setups do not necessarily have to compete with each other but serve different options and purposes, including the need to foresee accessible and democratised biodesign practices (Butoliya, 2024).

Biodesign labs identity

Until now, biodesign has been performed as a "frontier" discipline in different and emerging settings; as such, structural and linguistic uncertainties still characterise it. Structural uncertainty is derived from the variety of frameworks and working conditions, which is also highlighted by this study's findings. Linguistic uncertainty refers to the different names and definitions with which places where biodesign is practised label themselves, from (bio)makerspace to (biodesign) studio (Naito and Botero, 2024). Moreover, this uncertainty can also be attributed to the lack of explicit reference between some of these workspaces and biodesign as a discipline; in fact, biomakerspaces or community labs might not refer to biodesign, which is instead quoted in design universities' lab spaces. These uncertainties are given by the novelty of these spaces and of the biodesign phenomenon and discipline, also highlighted by a limited body of knowledge regarding the study of community and design laboratories for life sciences exploration by non-experts. Within this study, we refer to *Biodesign Laboratory* as a "workplace dedicated to hands-on biodesign experimentations and research, as well as to biodesign dissemination and teaching."[2]

Among the places where biodesign can be practised today, biomakerspaces (or DIYbio community spaces) are perhaps those with a more precise definition and identity in literature. They are often defined as informal learning environments for an exploratory and amateur audience serving a broader community outside of the academic setting (Buck, 2022; Walker et al., 2023). In a recent study, Walker and colleagues (2023b) describe community labs as informal learning environments that play a crucial role in STEM education (interestingly, the authors do not quote biodesign). Their study highlights similarities between community labs and makerspaces based on their focus on artefact creation and the culture of knowledge sharing and collaboration. The difference between the two is mainly related to the emphasis on life science topics, which community labs focus on. The latter also differ from typical life science labs, including other learning spaces and tools like audio, video and DIY-makers tools. Community labs are open for all genders, age groups and backgrounds; these spaces can provide access to places, tools and "communities of expertise that reduce knowledge threshold for participation," facilitating the novices and fastening the involvement of participants with no or little background in life sciences.

There is still minimal knowledge concerning the infrastructures supporting biodesign practice and education. Naito and Botero (2024) detail the infrastructures for designing with living organisms in spaces which promote making practices, highlighting that this space's infrastructural design often points toward conditions that are addressed differently in each context, showing extreme adaptability. Their study reports that the bio-setup for wet fabrication techniques is frequently done in repurposed spaces, especially suitable for entry-level work with biological materials; here, the pre-existing building features highly influence the workspace layout. Often, these spaces foresee a central workspace to be adapted according to specific needs, primarily for short-term and multi-occupant sporadic work (e.g. workshops). Despite the freedom given by this setup where "messiness" is tolerated, this is not ideal for working in a more established way with living organisms. The second typology of infrastructures they describe are those characterised by gradient zones of sterility to provide clean work areas while also maintaining flexibility. Still, their study highlights the general precarious condition of these places, linked to the lack of space or equipment; the latter often readapted through DIY and low-tech solutions. In addition to the tools required for working with living organisms, their slow growth process is also highlighted as a critical point regarding storage space in incubators and protected environments (ibid.).

Crawford (2023) suggests that fixed and unfixed aspects should be considered when setting up a design wet lab. Among the fixed ones, there are, for example, the need for storage space, safety protocols for the disposal of chemicals and biological agents, cleaning and maintenance of the lab, personal protective equipment, running water (possibly deionised filters) and electricity supply, an area set for aseptic work, a fridge, a flammable cabinet, a lab management plan according to the biosafety levels (BSLs). The unfixed aspects to consider are instead the type of work the lab wants to focus on, the number of people working in the lab and the organisms processed in the lab; this latter aspect determines species-specific equipment and consumables.

Being biodesign a hybrid approach across scientific and creative methods, Biodesign Labs have much in common with both scientific labs and Fab Labs. For example, they share with the latter DIY and open-source philosophies, a community-oriented audience, the learning-by-doing approach and their supportive role in education. If Fab Labs target more design and engineering, introducing new manufacturing techniques such as 3Dprinting and laser cutting (Alía et al., 2019), Biodesign Labs support design, art and science introducing biofabrication techniques and experimentations with different living organisms. Biodesign labs also inherit core features from conventional scientific labs for integrating biological systems with design principles and processes. To do so, they must carefully consider spatial organisation, safety protocols, interdisciplinary collaboration and specific technological infrastructure. Moreover, they both aim to foster innovation through controlled experimentation, scientific methods and translational applications.

This study addresses the need for clearer typologies and infrastructural guidelines to support the discipline's growth while maintaining its inclusive and interdisciplinary nature. Future efforts to define and systematise biodesign laboratory environments will strengthen the field's identity and promote accessible, innovative practices across diverse contexts. The survey results presented here aim to contribute to the still limited literature on Biodesign Labs thanks to a transversal study, involving twenty-four Biodesign Laboratories, that can offer an overall vision of the current state of the art regarding the places where biodesign can be practised and taught in a (scientific, academic or public) community framework.

Methods

This study points to gathering details of the current multifaceted structures in which biodesign is performed for educational, research and creative purposes, aiming to clarify the role of workspaces and infrastructures in supporting transdisciplinary research between design and science.

Online surveys can be a valid qualitative research tool to frame "nuanced, in-depth and sometimes new understandings of social issues" (Braun et al., 2021). Here, we describe the use of an online qualitative survey as a tool to gather information directly from biodesign lab spaces. This method, combined with the study's online advertisement, supported the coverage of wider geographical areas, allowing us to reach realities outside our contacts' network and gather data for comparability among different Biodesign Labs worldwide.

The survey was conducted between May and July 2024, using Google Forms as a data collection tool to set up the open e-survey. Respondents were allowed to provide open-ended answers, allowing them to add their perspectives and details beyond the predefined options (Ihls and Pollini, 2024).

The survey was carried out by sharing the ongoing study on various events and online platforms; it was presented during the Biodesign Challenge Symposium,[3] and shared via mail invitations (through the authors' contacts and knowledge in the sector) and social media (Instagram and LinkedIn from the authors' accounts and the Biodesign Challenge newsletter). Twenty-four Biodesign Labs participated in the open e-survey, covering eleven countries, different years of foundation (Figures 1 and 2) and a wide range of settings, including community labs, scientific labs and Biodesign Labs created in design universities.

Figure 1. Visual mapping from the participating labs.

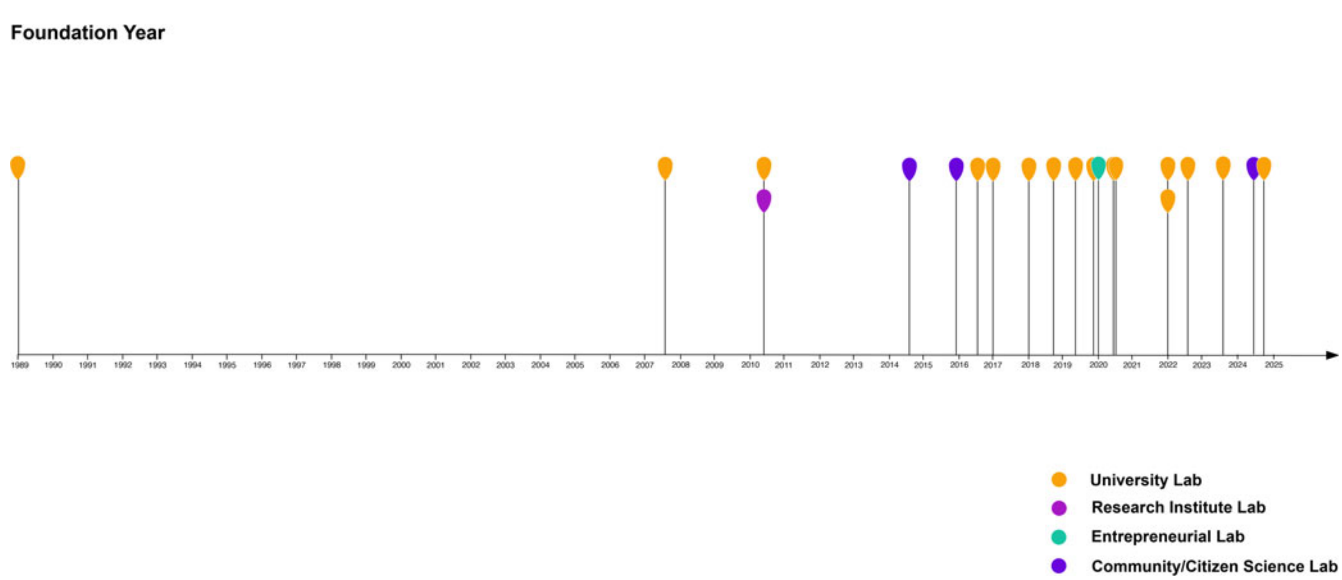

Figure 2. Linear visualisation of the foundations of the participating labs.

The online survey form had an introductory text clarifying the goal, the lexicon and the survey's target, explaining that the study aimed to define better the places and settings in which biodesign is performed. The authors specified that the meaning of biodesign was intended broadly in this study as a nascent hybrid discipline across design and science. Moreover, we clarified the target of the survey aimed at both low-tech and high-tech contexts, but with the requirement that the survey respondent should be someone who knows the laboratory dynamics inside out, such as heads of labs, laboratory managers, staff or designers who know the spaces, infrastructures, history and philosophy behind the lab well.

The survey contained three sections. The first, specifically for internal use, requested contact information and the general background of the survey respondents; the second section asked for visual content (images of floor plans, photos of the Laboratory and logos) to be shared for further analysis of the different biodesign spaces. Finally, the third section focused on describing the workspaces, articulating the discourse in 24 questions that could provide more details on the nature of the spaces. In this third section of the survey, in addition to temporal and geographical data, the following parameters were queried: role of the survey participant and their professional background, professional orientation of the lab concerning the disciplines worked on, the funding situation and size of the lab (employees and users), institutional and curricular connections, methodological orientation (scientific vs artistic research, as well as open-source vs patent work), scale of the work carried out, selection of materials/organisms, equipment used, BSL and degree of sterility. The specific parameters surveyed were supplemented with two open questions about the overall philosophy and a general lab description. The authors chose these parameters to capture a comprehensive understanding of social, economic and professional factors and explore potential interactions and correlations between laboratory equipment and biodesign practice.

We acknowledge that the current sample of testimonies has some spatio-temporal limitations. The survey would have covered a potentially global geographic area; thanks to this tool, testimonies from eleven countries have easily been collected. However, the geographical intensity of the biodesign laboratories in this study should not be regarded as fully representative, as the voluntary participation of the laboratories was also partly influenced by the authors' local network. Moreover, the data collected are a "momentum portrait" of an expanding phenomenon that will probably change as the biodesign scene progresses quickly, especially in the last 15 years (as shown in Figure 2).

An overview of the current state of biodesign labs: survey results

This paragraph reports the results of the third section of the survey, which focused on the spatial and working models of the Biodesign Labs surveyed. The survey responses were processed and converted into numerical values using a Microsoft Excel spreadsheet. The names of the institutions were anonymised in the survey results for better comparability and data protection for the participants. Moreover, the photographic material reported in this article is part of those cases for which the participants granted permission for publication. The results reported in this paragraph are the direct data gathered from the survey and can already give a first overview of the phenomenon. To draw more in-depth conclusions, these results will be further discussed in the following paragraph regarding clusters of information and early trends that emerged from the Biodesign Labs survey.

The survey confirmed the eclecticism of the spaces dedicated to biodesign, which appears to be a conceptual macro-category for activities with different domains and purposes. A varied picture emerged when asking participants about the types of activities supported in their laboratories (RQ3).[4] Open answers revealed that most workspaces in which biodesign is performed involve a variety of collateral disciplines, the majority of which are associated with material design (92%) and bioart (46%); interestingly, one answer highlighted how biodesign can also touch on topics such as biodiversity, craft and culture preservation. This also applied to the backgrounds of the participants (RQ 1 and 2). Although most respondents (80%) were the laboratory's managers or initiators, their professional backgrounds varied significantly. A total of 46% of those surveyed said they had a design background; a total of 21% were represented from the field of life sciences, 9% from biodesign, while the other disciplines (architecture, engineering, electronics, interaction design/media art, material engineering and biochemistry) were each listed with 9%.

Regarding geographical background (RQ5), eleven nations were represented in the survey. European biolabs made up the largest share, with 19 labs in total. The US was represented with 3 labs, and Japan and Colombia followed with 1 lab each. However, it should be emphasised that the geographical distribution only allows limited conclusions to be drawn about the absolute distribution of biodesign labs, as the individual backgrounds of the researchers (Germany and Italy) and their local networks are likely to play a distorting factor in the labs participating in the survey. As far as the running times of the labs are concerned (RQ12), most labs are relatively young: 92% were founded between 2010 and 2024, reflecting the biodesign field's recent growth in the last 15 years.

Regarding the operation of the labs in terms of employees (RQ6), we determined a range from no employees to over 20 employees. However, small Biodesign Labs with 1–5 employees made up the largest share at 71%. The rest was divided – with one abstention – (4% no employees, 8% 5–10 employees, 13% >10 employees). (RQ7) However, there was a more balanced distribution in the number of users of the labs: 46% stated that they could accommodate between 0 and 10 users, 21% had rooms for 10–20 users and 29%, in turn, had capacity for over 20 users; here too, there was one abstention.

Among the 24 Biodesign Labs that participated in the survey, 19 confirmed to be connected to a university, 3 were community labs for citizen science, one was an entrepreneurial lab and one was a research institute (RQ8). The majority (79%) of the labs connected to universities are linked to a specific course of study (RQ10); asking in detail about the discipline of these courses (RQ11), it emerged that 25% of the Biodesign Labs are directly linked to the biodesign discipline and another 25% to design, 12% were linked to life sciences, 8% to architecture, followed by 4 labs each related to one of the following disciplines: material science, engineering, synthetic biology and art.

Asking the Biodesign Labs to define themselves as more low-tech or high-tech (RQ4), three labs answered that they were low-tech, while only two responded that they were high-tech; the majority positioned themselves in an intermediate area slightly oriented towards a high-tech setting. Furthermore, by asking if they defined the lab as more oriented to science or art and design (RQ9), we obtained 4 placements on scientific orientation and 3 on design orientation; however, once again, most labs placed themselves in an intermediate area. (RQ21) A similar distribution also emerged when asked whether the labs were more research and publication-based or teaching and experiment-based. Here too, the majority (42%) stated an intermediate status. Only 5 laboratories mentioned a pure teaching and experiment approach and only 3 a pure research and publication orientation. However, a deviation was observed when it came to the question of the orientation between patents or open-source approaches (RQ22). Here, 92% of the labs surveyed positioned themselves at least "between patent and open-source" approaches up to pure open-source work. None of the labs mentioned a purely patent-oriented practice; only two positioned themselves towards "rather patent-oriented" on the spectrum. Therefore, we can notice a correlation with the previous question, indicating how the lab activities modify its assets and vice versa; a deeper discussion on this aspect will be presented in the following paragraph.

The 42% of the respondents to the survey stated that the laboratory has been created specifically for biodesign activities (RQ13); however, half (50%) refer to spaces acquired from other design or science laboratories and facilities. This shows how biodesign is often taught and practised in hybrid spaces, which exploit pre-existing structures by adapting their instrumentation or relying on scientific structures serving multiple disciplines. This aspect is partially confirmed also by three further questions on sterile conditions in the workplace: When asked how controlled the laboratory environment is (RQ18), only three respondents stated that they have a cleanroom (ISO Class 8), six declared that they work in a workshop environment characterised by dust and particles; the remaining majority of the labs describe an intermediate situation. We can imagine those latter environments as more rigorous in biosafety and cleaning protocols than a workshop space, but still unable to guarantee that they can work successfully with the most delicate organisms and procedures.

The two following questions are also highly related to this topic; in fact, we asked whether the laboratory is an open space where lab research, desk research and creative practice coexist or whether specific labs are defined by separated environments (RQ19): The 46% declare that experimental activities take place in closed laboratories and are separated from desks and more creative activities; however, for a good 54% the lab is an open space where design and science activities happen simultaneously. Separated environments can help set workspaces for more sterile work. Biohazard levels, more commonly referred to as "biosafety levels," are classifications of safety guidelines to be applied in microbiology laboratories. There are four classifications of BSLs, each with specific recommendations depending on the microorganisms' hazard handled when performing laboratory procedures (Bayot and King, 2024). The most high-tech Biodesign Labs might have separate spaces dedicated to BSL1 or BSL2 work. When it comes to our survey (RQ20), 37,5% of the participants declare to have no safety level (among these, a couple of laboratories declare to follow the BSL 1 standards even if they are not certified as such), while 50% have at least one laboratory with BSL 1 and the 12,5% of the labs reach BSL 2.

(RQ15) In addition to the security levels and the controllability of the laboratory environment, we also asked about the scale on which the work was carried out. Here, we gave a possible spectrum from nano-scale (e.g. bioengineering) to metre-building scale (e.g. metre-size artefacts or building components). Only two Biodesign Labs positioned themselves at the extremes. The majority (38%) operate at the micro level, followed by millimetre-to-centimetre (29%) and centimetre-to-metre (25%). This is also in line with the previous results, which show that most environments in which biodesign is practised operate in a chimeric intermediate stage.

As far as the financial situation is concerned (RQ14), we found a balanced distribution: Half of the Biodesign Labs surveyed are secured with a permanent funding status, 8% are currently in a transit stage between temporary and permanent funding and 42% are in a precarious, time-limited financial situation.

As regards to the most experimented organisms in biodesign (RQ16), the survey shows that bacterial cellulose is the most tested, addressed by the 79% of the survey respondents, followed closely by mycelium and "bacteria, yeast and cells" (both experimented by the 75% of the labs), algae (67%) and plants (58%); synthetic biology seems to be a minority (17%), as well as working only with non-living bio-based materials (8%).

A pre-structured list with multiple-choice selection (RQ17) was provided to query the tools and equipment available in the laboratories, also giving the possibility to freely add equipment not included in the list. The items given for selection (21 items) were ranked in order of preference, with the first three places occupied by microscope, laboratory glassware and laboratory refrigerator (see Figure 3). Additional equipment added by the laboratories surveyed

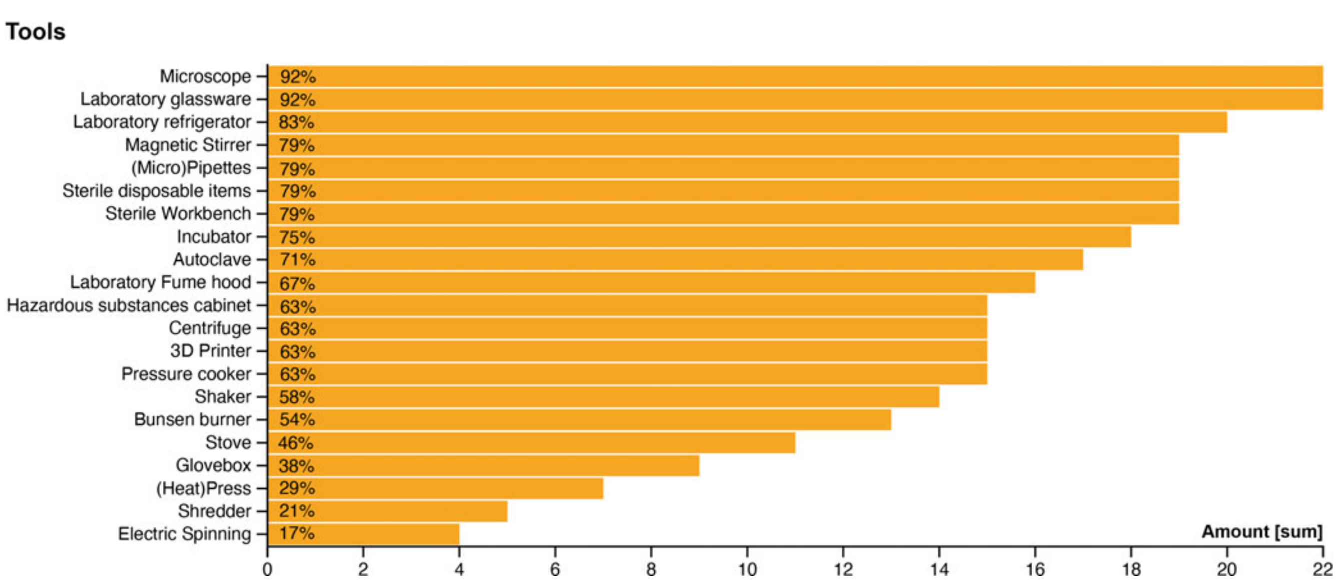

Figure 3. Equipment list of the labs, ranked by frequency.

resulted in the following list: 4K display, dishwasher, vacuum former, microwave, oven, pans and pots, precision scale, printer, safety and health applicants, photo equipment, wood workshop, exsiccator, distiller, freezer, vacuum sealer, laser cutter, various 2D printing tools (e.g. inkjet), halogen lamp steriliser, microtome, bento lab, pocketPCR, miniPCR, nanopore DNA sequencer, ultra-low temperature (e.g. –80) freezer, laboratory glasswasher, pH metres, sonicator, peristaltic pump, thermocycler, vortexer, dehydrator, water bath, RO machine.

The survey ended with two open questions addressing the definition and the philosophy of the biodesign workspace. When asked to give a personal definition of the Biodesign Lab (RQ23), more scientific-oriented labs let the leading research activities describe the space itself. In contrast, open and hybrid spaces have provided broader descriptions addressing recursive concepts, such as collaboration, cross-disciplinarity, sustainability and experimentation. Community labs primarily focus on collaborative practices, providing access for biodesign exploration to a diverse and multigenerational audience; here, open science and do-it-together philosophies rule, also preserving cultural heritage through traditional bio-techniques explorations. Collaboration is not only meant on a social level but also across disciplines: cross-disciplinary collaborations and transdisciplinarity are considered key in Biodesign Labs; many spaces offer hybrid settings for art, design and scientific research to benefit from each other. Sustainability is recalled as a crucial driver in the activities carried out in Biodesign Labs, whether related to circularity or sustainable materials and processes that can replace existing polluting ones with bio-based solutions. Another recurring aspect is the hands-on experimentation on material and living organisms. Experimentation is also quoted among the philosophies behind the lab establishment (RQ24) associated with critical making and research-through-design. Also the discourse on sustainability is recalled here, addressing more philosophical topics such as posthuman, post-Anthropocene and multispecies discourses. Open-source philosophy is another vital topic characterising Biodesign Labs, pointing to democratising research and community knowledge.

Despite this study's spatio-temporal limitations, the sample has been analysed as representative of an evolving trend in biodesign literacy; in the following paragraph, some crucial correlations among different conditions and settings of the Biodesign Labs have been drawn from the collected data in a more in-depth analysis.

Correlations between spatial conditions and working modes

Building on the previously presented data, this section explores how spatial characteristics, technical infrastructure and epistemic orientations interact in shaping Biodesign Lab configurations. To structure this analysis, we selected six axes from the survey data that reflect critical dimensions of biodesign practice: 1) Level of sterility (RQ 4), 2) Level of technical infrastructure (RQ18), 3) Scale of operation (RQ15), 4) Knowledge-sharing philosophy (patent vs. open-source, RQ22), 5) Epistemic orientation (science vs. art/design, RQ 9), 6) Primary working mode (research/publication vs. teaching/experimentation, RQ21) (cf. Figure 4).

These axes were selected to capture core operational and epistemic dimensions that define the socio-technical role of a Biodesign Lab. Together, they reflect how a lab is equipped, shares knowledge and balances scientific, artistic and pedagogical objectives. They also offer a comparative framework linking infrastructural qualities with spatial and institutional identity, as further discussed in the analysis of lab typologies. To make these abstract dimensions tangible and comparable across cases, we visualised them using radar diagrams, each representing the unique profile of an individual lab. This enabled us to identify patterns and emergent typologies across the 24 labs surveyed. Each of the six diagram axes represents one extreme of one question. For example, one question focused on the attitude towards sharing knowledge: "If your laboratory were to develop a new material or process, how would you proceed? 01 = patent-oriented, 05 = open-source-oriented." If participants indicated a strong open-source orientation (with a maximum weighting of "5"), this can be recognised by a strong deflection, while a tendency towards patent orientation is visible by an approach to the polar zero point. This correlation resulted in an individual profile for each of the participating Biodesign Labs, which are shown in Figure 5.

The wide range of forms reflects the heterogeneity of biodesign practice already mentioned in the introductory section. Nevertheless, three significant profiles – Scientific-Analytical, Biotinkering-Explorative and Balanced All-Rounder – can be identified in the diversity, which becomes clear through a formal-aesthetic comparison and are distinguished by their combinations of sterility, scale, equipment and epistemic orientation.

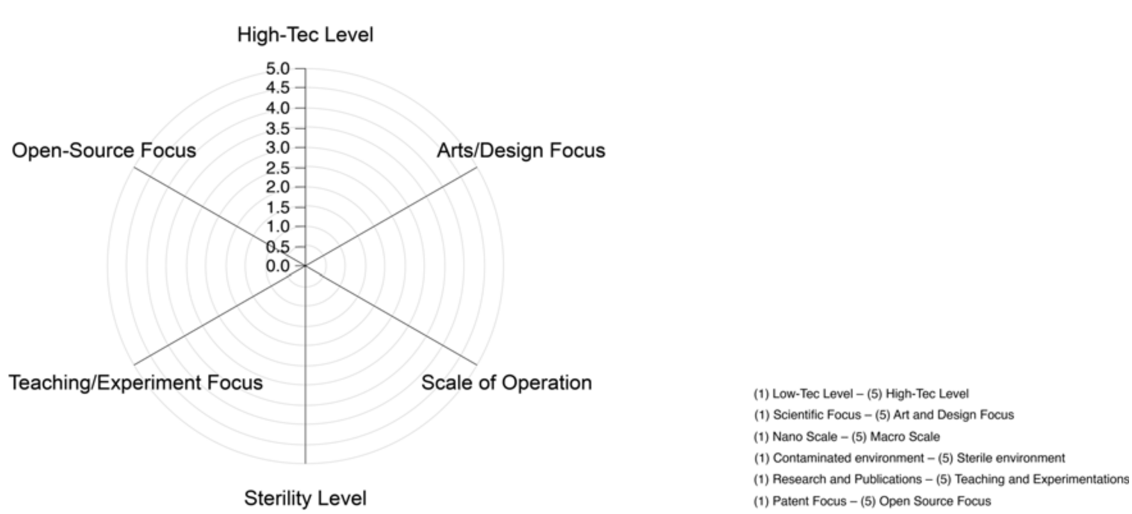

Figure 4. Blank radar matrix with descriptions of the axes' values.

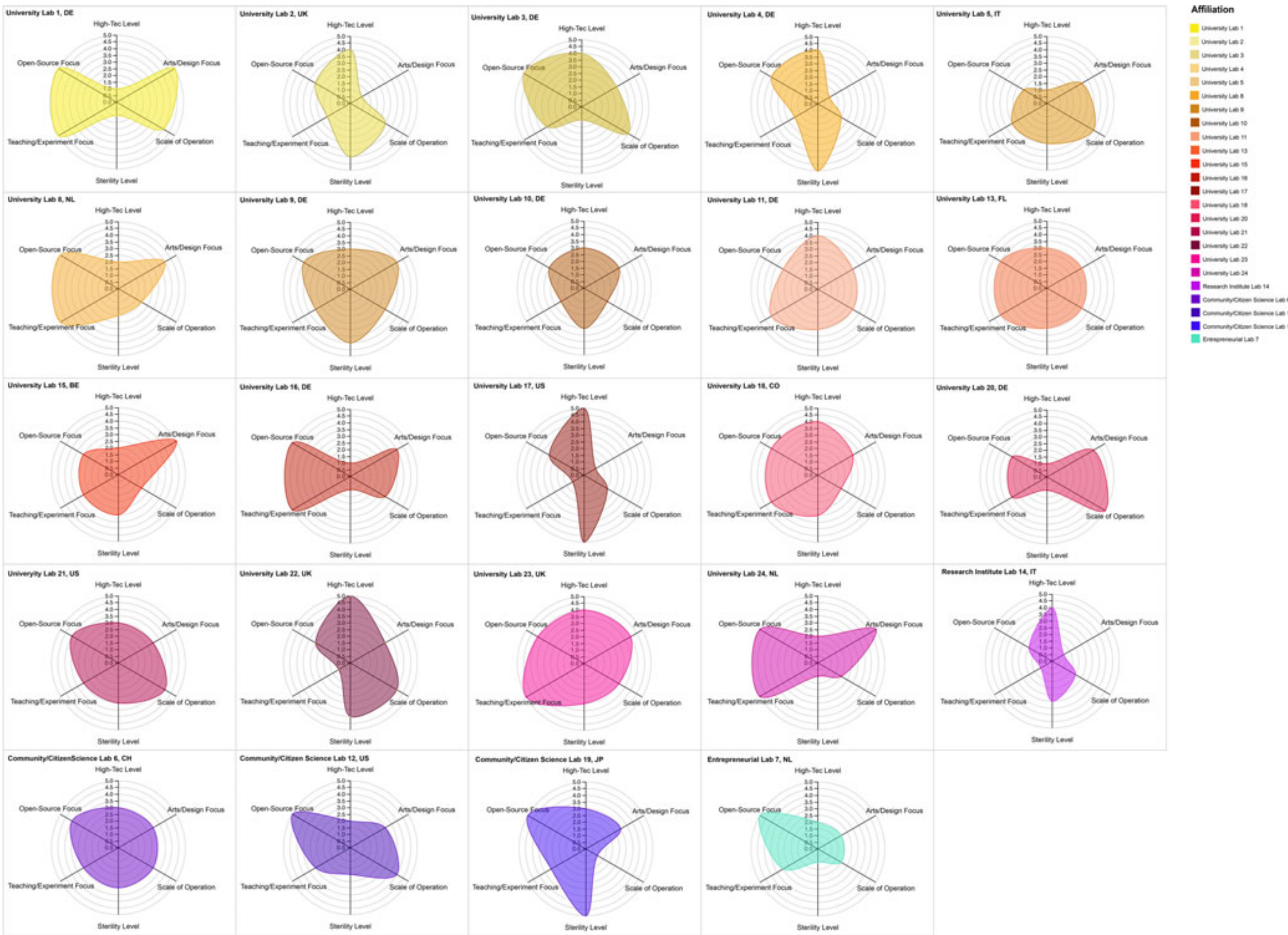

Figure 5. Correlation-profiles of all 24 participating labs.

The scientific-analytical lab

The decisive, comparative factor for this profile was a technology level of 4 or higher and a scientific focus of 1. Scientific-analytical laboratories (Figure 6) are therefore characterised by a high-tech level, a strong scientific focus and a correspondingly high level of sterility. For the most part, this is accompanied by work on a micro-scale. For instance, working with genetically engineered bacteria for colour production requires precise liquid handling tools, clean benches and incubation chambers operating at microliter scales. Such micro-scale precision is difficult to replicate in non-institutional or low-budget contexts. The high level of technical equipment

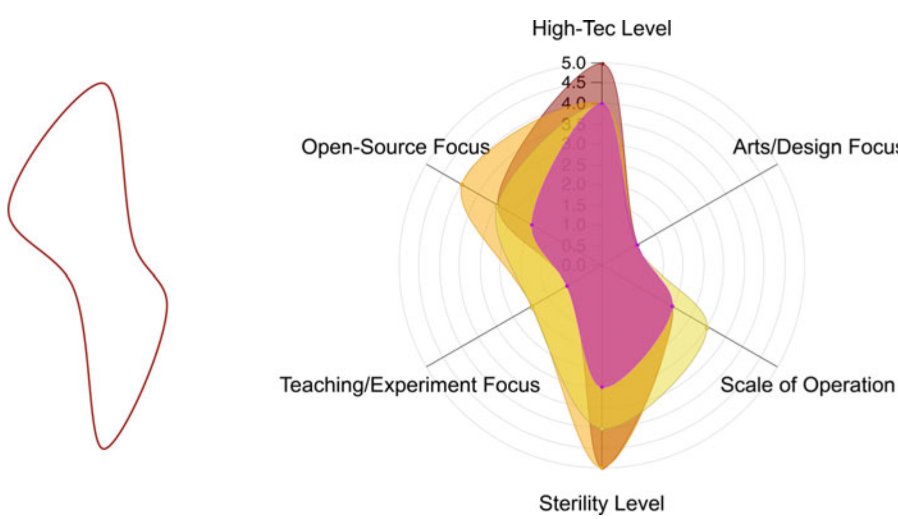

Figure 6. Correlation scientific-analytical lab.

also goes hand in hand with a tendency towards more research-based, publication practices rather than experimental, creative working methods. While one might expect these labs to prioritise proprietary innovation, many still maintain a balance between open-source and patent-oriented approaches – likely influenced by academic publication standards and funding models.

The biotinkering-explorative lab

While the scientific-analytical laboratory is characterised diagrammatically by a narrow, vertically curved wedge shape, the horizontal, loop-like shape of the biotinkering-explorative laboratory represents a supposed antithesis to this. The criterion for that profile was a maximum value of 5 on the scale *patent orientation vs. open-source orientation* in combination with a maximum value of 5 on the scale *research and publication vs. teaching and experimentation*. Accordingly, the biotinkering-explorative lab is characterised by a radically democratic open-source idea, which not only correlates with a maximum tendency towards teaching and experimentation instead of research and publication but also pursues a strong artistic-creative orientation. These labs operate across a broad spectrum of scales, from microbial fermentations in glass jars to metre-scale installations. Their approach to scale is often pragmatic and resource-driven, relying on DIY adaptations rather than standardised equipment. Sterility levels are generally low but remain sufficiently adaptable to support experimental prototyping with living materials. The labs' emphasis on openness and material exploration is closely linked to artistic and critical design practices. The loop-like shape of their radar profiles reflects this distributed and multifocal character, suggesting an exploratory logic rather than a centralised functional core (Figure 7).

The balanced all-rounder lab

The third profile that could be formally and aesthetically identified was the balanced all-rounder lab (Figure 8). The

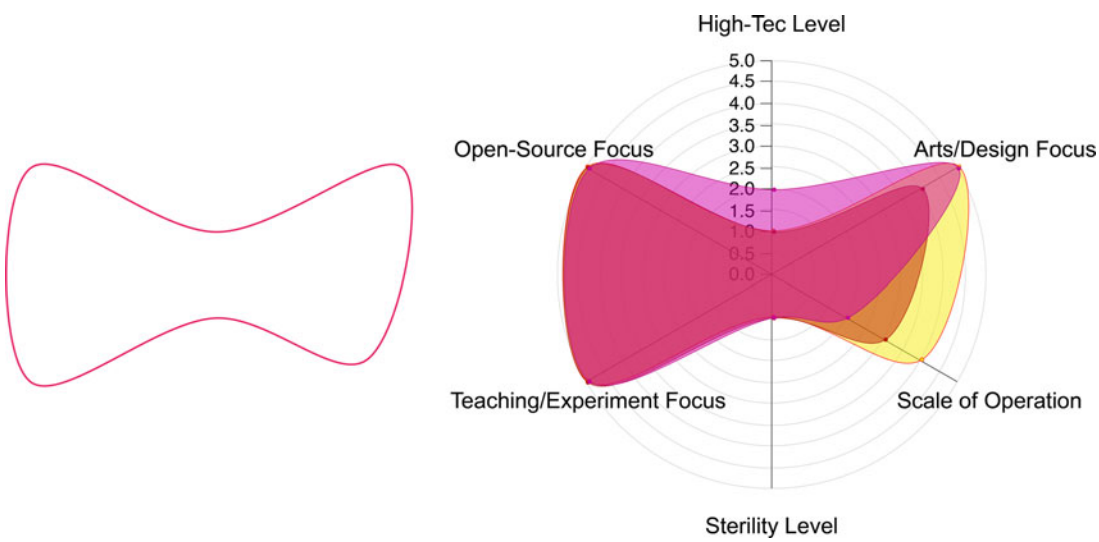

Figure 7. Correlation biotinkering-explorative lab.

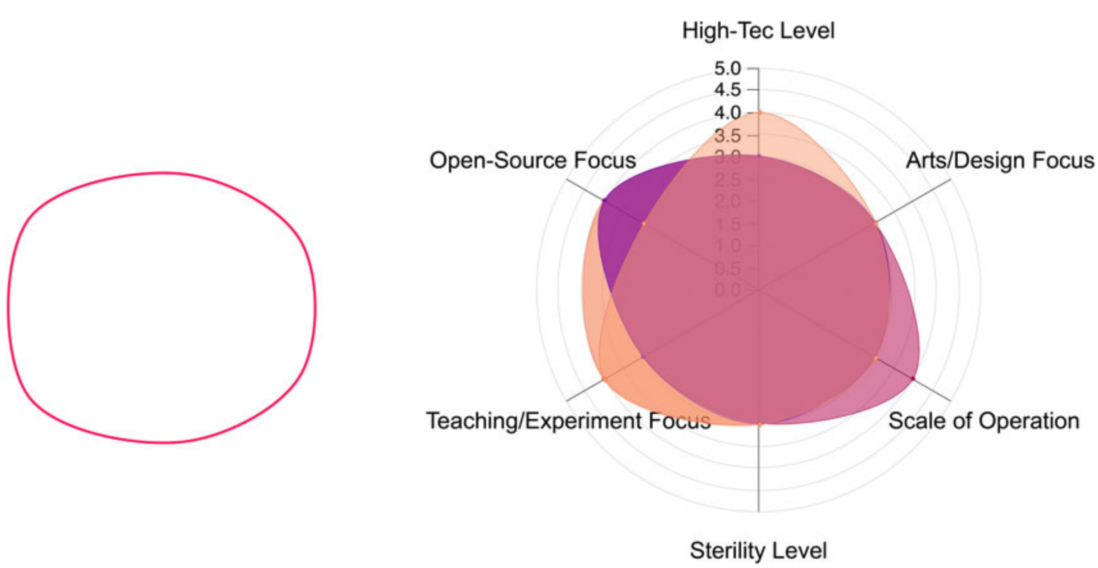

Figure 8. Correlation balanced all-rounder lab.

institutions that qualified as such gave the same value for at least four of the six scales surveyed and only had a deviation of ± 1 from the other four for the two remaining values. The resulting, almost circular-symmetrical shape is evidence of a balanced orientation, suggesting multi-directional openness and institutional adaptability. Those labs, which represent the largest category (5 representatives) of the analysed profiles, are neither particularly scientific nor extremely design oriented. The technical equipment and sterility level rank in the midfield, as do the scale of operation and open-source orientation. It can be assumed that the balanced all-rounder labs represent a relatively wide range of practices and organisms, emphasising the biodesign discipline's hybrid nature. To operate as an all-rounder, labs typically need a robust yet flexible infrastructure – not necessarily high-budget, but highly adaptive. This allows them to engage in both speculative design and experimental science without overcommitting to either pole. Hence, what distinguishes the balanced all-rounder is not necessarily access to the highest-end tools but rather the flexibility of infrastructure and institutional tolerance for ambiguity. These labs are likely to benefit from cross-departmental collaboration and leadership with experience in both science and design domains.

While the profiles are not rigid categories, some structural barriers exist to shift from one to another. Without access to biosafety certification, advanced lab equipment or long-term institutional support, it is challenging to establish a Scientific-Analytical lab. Conversely, becoming a Biotinkering-explorative lab requires openness to less formalised, sometimes unpredictable methods – a mindset not easily adopted in traditional academic scientific contexts. The Balanced All-Rounder often emerges from strategic alignment across departments, allowing for adaptive scaling between modes of practice. Notably, institutional affiliation or geographic location did not consistently predict lab typology. For example, a community science lab does not necessarily stand for a maximum open-source orientation, just as a university-affiliated lab does not automatically entail a high degree of research specification. The profile characteristics can occur in a wide variety of institutional contexts and are the result of an interwoven negotiation process regarding the laboratory orientation – be it spatially or in modus operandi. A similar phenomenon applies to the geographical distribution: although most participating laboratories are located in Central Europe, votes were also collected from Japan, the USA and Colombia. No significant correlation was found between the geographical zone and the characteristics of a specific laboratory type. This underscores the need to read labs as situated socio-technical constructs, not as rigid categories. Furthermore, the individual assessment factor must be considered in the correlation results. The answers for the respective Biodesign Labs are a snapshot, in most cases, based on the assessment of a single person. Whether this person's answers tend to classify a lab as All-Rounder, Biotinkering-Explorative or Scientific-Analytical is partly in the eye of the beholder. Regarding the visual photographic material of the laboratories, it is only possible to categorise the three lab profiles outlined to a limited extent. More detailed spatial mappings – such as floor plans, material flows or equipment clustering – could provide deeper typological insight for future research. Notably, none of the labs categorised as scientific-analytical submitted visual documentation. This may be attributed to non-disclosure agreements (NDAs) or intellectual property (IP) restrictions, common in highly research-driven environments. Thus, Figures 9 and 10 only shows examples of biotinkering-explorative or balanced all-rounder lab types:

Despite the photographic material available, there does not appear to be a consistent spatial or formal pattern that matches the analytical profiles developed in this study. This might indicate that the profile identification of a Biodesign Lab is not influenced by purely external characteristics (spatial arrangement, equipment) but is also shaped by social and material cultures such as experimental working methods or open-source approaches.

Conclusions

The study presented here aims to explore and highlight the diverse frameworks in which biodesign is currently addressed for educational, research and creative endeavours. The results showed how workspaces and infrastructures are evolving to support transdisciplinary research between design and science in different configurations. The qualitative data collected from the survey provides an overview of the laboratories' socio-technical role in supporting biodesign and the nascent derived practitioners.

In particular, the study confirms a significant heterogeneity of biodesign practice and the associated locations; further analysis of the interactions and trends derived from the collected data helped to deduce three Biodesign Lab profiles, which were specified as scientific-analytical, biotinkering-explorative and balanced all-

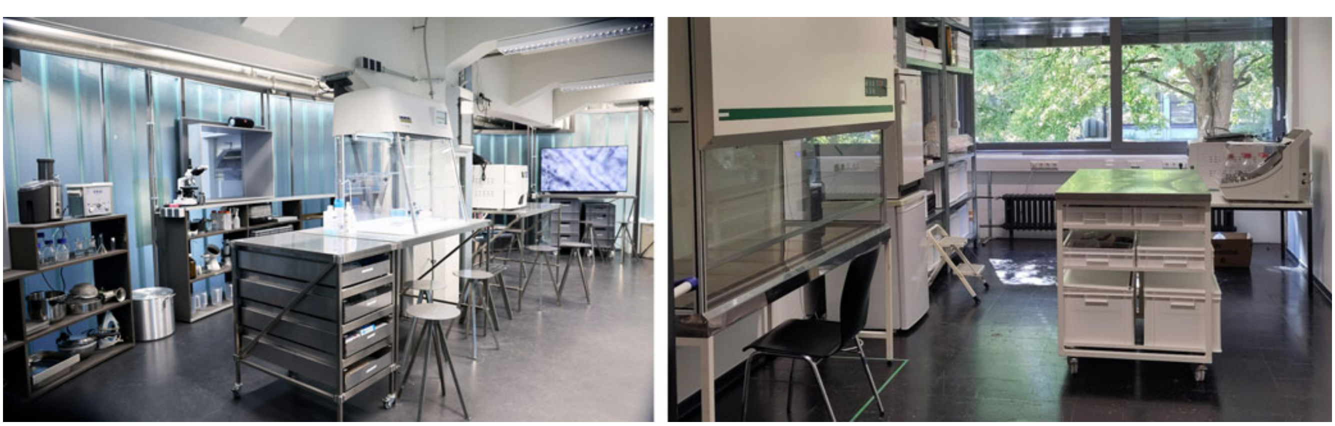

Figure 9. Left: Bio Design Lab, University of Arts and Design, Karlsruhe, Germany. Right: Biolab, Kunsthochschule Kassel, Germany. Both are examples of Biotinkering-explorative Lab.

Figure 10. Left: Biolab, Burg Giebichenstein Halle, Germany. Right: Grow Lab, Central, Saint Martins, London, UK. Both are examples of Balanced All-Rounder Lab.

rounder labs. The profiles show initial reciprocal effects between biodesign practice and the spaces or infrastructures in which it takes place. It cannot be ruled out that further profiles may be added in the future as the number and differentiation of biodesign spaces increase. In summary, it can be said that in the comparative analysis, the different types of Biodesign Labs cannot be weighed against each other in terms of quality, efficiency or impact. Rather, various profiles and topologies coexist equally. In terms of their equipment and mission philosophy, the laboratories can only be standardised to a limited extent but rather are extremely situated – a circumstance probably also due to the highly interdisciplinary and entangled nature of the biodesign discipline. The study saw many Biodesign Labs positioned in an intermediate zone in several divergent features, especially regarding the orientations between low or high-tech environments, design or science orientation, research or education aptitude and scale of operation. This reflects the hybrid nature of biodesign – across different fields of knowledge, different organism and biofabrication techniques and adapting to different approaches – and was particularly resonating with the balanced all-rounder Biodesign Labs profile.

We acknowledge some geographical and temporal limitations in the data collected. The study highlights Biodesign Lab spaces as an evolving trend, so temporal limitations of the survey can foresee future reiterative investigations on the subject. For example, it would have been interesting to see how these labs have evolved over time, but this further comparison was limited by the current lack of data and literature on the topic. Previous research has highlighted that biodesigners can adapt to different workplaces, but their work and outcomes are also influenced by the lab settings in which they operate; therefore, further analysis would be beneficial to gain a deeper understanding of how the workspace defines and influences biodesign practice. Moreover, further investigations and correlations can be conducted with the same data set shared in the appendix.

Despite these limitations, the study gives a valid glimpse of how infrastructures that foster biodesign research and education are evolving to support transdisciplinary collaborations. The three distinct spatial typologies and frameworks highlighted in the study can serve as a better understanding of the different laboratory configurations and document the eclecticism and diversity of biodesign spaces, revealing how these labs support various disciplines and practice-based research activities.

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Data availability statement. The complete survey results are available in the appendix:

Ihls, J., & Pollini, B. (2025). From observation to operation: the role of lab spaces in Biodesign practice – Appendix. *Cambridge Open Engage.* https://doi.org/10.33774/coe-2025-ww7b0.

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Competing interests. The authors have no conflicts of interest to declare for this publication.

Ethics statement. Participants freely decided to contribute to the study. Informed consent was obtained from all participants, ensuring their privacy and confidentiality. Data were collected and anonymised to analyse them transparently, avoiding bias and ensuring accuracy. All images published in the article were selected upon consent.

Notes

1 For examples, the MA Biodesign from Central Saint Martins, the Bio-Integrated Design (Bio-ID) MArch/MSc from UCL, and the IDE Design Master Class for Professionals in Biodesign at TU Delft, are among the first examples in UK and EU. See also further paragraph on study results.

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https://www.ucl.ac.uk/bartlett/architecture/study/postgraduate/bio-integrated-design-bio-id-marchmsc.

https://www.tudelft.nl/io/studeren/ide-design-master-classes/previous-master-classes/ide-master-classes-2023/biodesign.

2 This definition was also clarified in the introductory part of our survey. Full survey and results via Ihls, J., & Pollini, B. (2025). From observation to operation: the role of lab spaces in Biodesign practice - Appendix. *Cambridge Open Engage*. https://doi.org/10.33774/coe-2025-ww7b0.

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4 More details can be found on the appendix numbered accordingly.

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