Journal of Responsible Technology 25 (2026) 100154

Contents lists available at ScienceDirect

Journal of Responsible Technology

journal homepage: www.sciencedirect.com/journal/journal-of-responsible-technology

Responsible Research and Innovation-Labs: towards new forms of reflexivity in engineering and innovation practices

René von Schomberg *, Stefan Böschen, Julia Backhaus

RWTH Aachen University, Germany

ARTICLE INFO

Keywords:
Living labs
Responsible innovation
Responsibility
Anticipatory governance

ABSTRACT

This article explores the integration of Responsible Research and Innovation (RRI) principles within living labs, particularly focusing on engineering and innovation practices. It reviews the evolution of living labs over the last 20 years, their roles in fostering co-responsibility among stakeholders, collaborative knowledge production and directing innovations toward socially desirable ends. It proposes the concept of Responsible Research and Innovation Labs (RRI Labs) tailored for engineering practices.

1. Introduction: embedding co-responsibility in the innovation process

In today's knowledge societies, innovation processes are increasingly opening up, with the roles of stakeholders and citizens gaining prominence. A wide array of concepts has been developed to justify and guide these developments. Participatory Technology Assessment (Hennen, 2012; Grunwald, 2018), the Democratisation of Innovation (von Hippel, 2005), User-Centred Innovation (Marchi et al., 2011), and Participatory Design (Hyysalo & Johnson, 2024) are examples of attempts to grasp this phenomenon. Within these approaches, stakeholders and citizens are seen as playing productive roles—improving functionality, enhancing usability, and fostering acceptance.

Questions of responsibility and accountability are integral to these participatory processes. The concept of Responsible Research and Innovation (RRI) has therefore embedded the idea of *co-responsibility* as a constitutive element (von Schomberg, 2013). RRI emphasises mutual responsiveness and coordination among actors in innovation processes, aiming to mitigate power asymmetries and provide innovation with a socially desirable direction. However, this raises a practical challenge: how can such coordination be realized in specific contexts?

Addressing this question involves examining the social construction of accountability, which encompasses not only individual responsibility but also collective agreement and institutionalization. These dynamics also become visible in experimental settings.

Living labs offer a promising framework for such experimentation. They are designed to bring together diverse stakeholders to coordinate research efforts and engage in collective problem-solving. In parallel, various science-informed guiding principles have emerged to steer these coordination efforts. Overarching principles such as sustainability and resilience, as well as specific principles for fostering responsible research and innovation (Owen et al., 2021. Von Schomberg, 2013, 2019; von Schomberg et al., 2023), serve as normative anchors for these processes.

While a balanced relationship among stakeholders is widely acknowledged as crucial (Carayannis & Campbell, 2009; Compagnucci et al., 2021), there remains a notable lack of systematic approaches for implementing such guiding principles in real-world experimental contexts. This gap is particularly acute in the preliminary stages of science, technology, and innovation development. Experimentation platforms can serve as important sites where responsibilities are negotiated and institutionally embedded from the outset.

Two broad cultural-institutional models of experimentation can be distinguished. The first is a technocratic model, in which experts set objectives and design solutions that are implemented in a top-down, technology-push manner. This model reflects a "predict and control" mindset, focused on efficiency and precision in achieving pre-defined goals. However, as Borrás and Edler (2014) argue, this approach limits adaptability and overlooks the complex, interdependent nature of societal challenges.

To address these limitations, a second, more pragmatic model has been proposed. It promotes iterative, participatory processes in which a range of actors—policymakers, industry, business, and civil society—collaboratively shape and define solutions. Yet, the key question remains: how can such a model be structured and implemented in a co-

* Corresponding author at: Human Technology Center, RWTH Aachen University, Theaterplatz 14, 52062 Aachen, Germany.
E-mail addresses: vonschomberg@inbox.eu (R. von Schomberg), stefan.boeschen@humtec.rwth-aachen.de (S. Böschen), julia.backhaus@humtec.rwth-aachen.de (J. Backhaus).

https://doi.org/10.1016/j.jrt.2026.100154

Available online 29 January 2026

responsible way?

This paper argues that innovation and transformative change can only be effectively advanced through structured formats for stakeholder engagement and knowledge acquisition that are geared toward socially desirable objectives. For that purpose, this contribution proposes the concept of a Responsible Research and Innovation-Lab (RRI-Lab*)*. Based on a critical review of the conceptual evolution of the main forms of living labs of the last 20 years, e.g. Urban Living Labs, Social Living Labs, and Living Labs supporting societal challenge-based mission-oriented research and innovation, the paper established essential living lab features and evaluated the extent they contributed to responsible research and innovation. Furthermore, the paper identifies several conceptual shortcomings for enabling living labs to address specifically engineering practices. These concern the employment of foresight, responsible design of technology and an open ecosystem innovation approach. Finally, the paper integrates all relevant current and proposed new features of living labs into a proposal for a Responsible Research and Innovation-Lab (RRI-Lab) which is dedicated to engineering practices and elaborates how specific features of living labs enable reflexivity in the knowledge acquisition and innovation process. As such, it identifies specific features of living labs that can ensure alignment of the knowledge acquisition and innovation process with societal values.

The structure of the paper is as follows:

In Section 2, we discuss the current discourse on RRI, particularly to what extent the alignment of research and innovation with societal values is conceptualised and achieved.

Section 3 elaborates on the core elements of living labs as platforms for collaborative and distributed knowledge production.

Section 4 traces the development and learning trajectories of various living lab models, assessing their contributions to RRI.

In section 5, the case is made for the establishment of dedicated living labs tailored to engineering practices. RRI processes must be context-specific, yet the RRI literature has concentrated on research and technology development in a generalised, abstract manner, thereby overlooking the operational realities of innovation in engineering practice.

By focusing on this gap, this paper aims to contribute to the further development of RRI, particularly in its application to real-world innovation and engineering contexts.

2. Fostering transformative change with responsible research and innovation

Responsible Research and Innovation (RRI) has gained increasing importance since its introduction as a cross-cutting issue under the European Union's Framework Programme for Research and Innovation, Horizon 2020 (2014–2020) (European Commission, n.d.). It later became an operational objective of the Strategic Plan for Horizon Europe (2021–2024), the EU's current research and innovation framework (European Commission, 2021). Several EU Member States have also launched national initiatives to support RRI, often through their research councils—for example, in the United Kingdom, Norway, and the Netherlands. The concept has further resonated beyond the EU, finding uptake in countries such as the United States, South Africa, Australia, and China, where it was incorporated into the national Five-Year Plan for science, technology, and innovation (2016–2021).

RRI emerged in response to the limitations of earlier "Science and Society" research funding programmes in many of these regions. According to Owen et al. (2021) and von Schomberg (2019), these shortcomings can be identified along four main lines:

1. RRI extends beyond the traditional scope of ethical, legal, and social aspects (ELSA) studies by actively shaping science and innovation toward addressing grand societal challenges. It is grounded in shared European values and global commitments such as the Sustainable Development Goals (SDGs). Institutionalizing RRI would therefore render research and innovation policy more value-driven.
2. It introduces a shift from ex-post ethical evaluations of emerging technologies to an ethics of co-responsibility, engaging stakeholders early and reflexively in the innovation process.
3. RRI moves beyond evaluating individual technologies, instead focusing on entire innovation processes. It calls for inclusive participation from all stakeholders, aiming to make innovation more manageable and socially directional.
4. RRI also seeks to address market failures in delivering socially desirable innovation outcomes. This includes elements of anticipatory governance (Guston, 2014).

Despite offering diverse perspectives, scholars agree that RRI necessitates a governance model capable of steering innovation toward socially beneficial outcomes. Von Schomberg's (2013, p. 63) early and widely cited definition captures this orientation:

"Responsible Research and Innovation is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)."

This definition was never meant to be definitive, but rather a starting point for a growing field of research and innovation practices. It highlights the limitations of conventional public policy, which typically governs science and technology through negative selection—mainly risk management—and assumes all innovation inherently contributes to societal prosperity. RRI breaks with this assumption by asserting that innovation can be directional. It places the power for socially desirable change in the hands of engaged stakeholders and citizens. However, this shift requires these actors to be incentivized—or even obligated—to become mutually responsive in terms of social commitments.

The European Green Deal (European Commission, 2019) is one such example of a collective social commitment that enables directional innovation. It embodies the institutionalization of co-responsibility, moving beyond traditional ethics frameworks that primarily focus on technological constraints (i.e., what we should not do). Instead, RRI encourages a constructive ethical approach, asking: what direction ought innovation to take?

Despite its promise, implementing RRI in practice has encountered significant barriers. Research, technology, and development (RTD) organizations and innovation actors often need to undergo substantial organizational change to align with RRI principles (Forsberg & Wittrock, 2023). Moreover, there is no single formula for implementing RRI, as it must be adapted to a wide range of technologies and innovation contexts—from healthcare and energy transition to agriculture and manufacturing. As a result, RRI implementation requires continuous organizational learning.

A responsible innovation practice must also aim to achieve desirable and acceptable impacts. Since these outcomes are often unpredictable, RRI must embrace collective experimentation (Nordmann, 2019). This approach is reflected in the evolving concept of Open and Responsible Research and Innovation (ORRI), which promotes an open, adaptive, and integrated model of research and innovation governance. By strengthening the role of relevant stakeholders in inclusive processes, ORRI allows scientific, technical, and societal innovators to better anticipate and respond to societal expectations.

In this framework, both the product (the outcome of innovation) and the process (the governance of innovation) are tightly interrelated. Effective RRI requires a coordinated and collaborative approach to both dimensions.

To support this integration, it is crucial to establish lasting ORRI capacities across all knowledge actors within the quadruple helix (academia, industry, government, and civil society) through tailored guidance for specific mission-oriented research fields—particularly in

the engineering sciences. Fields such as additive manufacturing and digital innovation present unique challenges and opportunities for embedding RRI principles. They require dedicated support mechanisms to translate the general ethos of ORRI into field-specific practices.

3. Distributed and collaborative knowledge acquisition: an issue for the governance of living labs

The establishment of living labs represents one of the most ambitious attempts to expand experimental practices into real-world contexts. These approaches cover a remarkably wide range of applications and have become ubiquitous in contemporary societies (e.g., Augenstein et al., 2022; Hossain et al., 2019; Schäpke et al., 2018; Schneidewind et al., 2018; Wanner et al., 2024). In the context of transformative innovation aimed at addressing societal challenges, living labs—especially real-world laboratories—play a critical role. Transformative innovations often unfold through experimental processes (Gosh et al., 2021) suggesting that living labs can provide a viable framework. Within these environments (e.g., Engels et al., 2019; Wanner et al., 2018), representatives from diverse stakeholder groups—often modelled as a "quadruple helix" (Compagnucci et al., 2021)—experimentally deploy innovations under real-life conditions and aligned with social goals. Living labs constitute a robust research and innovation infrastructure capable of addressing a broad spectrum of challenges—from testing individual products and services (Schuurman & Protic, 2018), to designing socio-technical environments (e.g., ambient-assisted living; Pallot et al., 2010), and even reconfiguring large-scale infrastructures like energy networks (Engels et al., 2019). They also serve as critical instruments for sustainability transformation initiatives (e.g., QuartierZukunft, 2020). In human–computer interaction research and development, living labs frequently tackle the digitalization of everyday life, human–robot interaction, and the creation of 'smart' everyday spaces such as homes and neighbourhoods (Alavi et al., 2020).

Universities have increasingly institutionalized such labs concerned with stakeholder collaboration and real-world experimentation in a specific field such as energy transition, autonomous driving or health and well-being. Backhaus et al. (2022) distinguish three types of university-based living labs: (1) maturing technological innovations through small-scale experimentation, (2) embedding innovations at scale with large-scale experimentation, and (3) driving sustainable transformation via stakeholder co-creation aimed at societal challenges. The typology highlights that university-based living labs differ not only in purpose but also in complexity, as broader stakeholder involvement intensifies contextual interactions, shapes patterns of inclusion and exclusion across local and translocal settings, and often relegates civic actors to consultative rather than decision-making roles (Backhaus and John, 2025).

These real-world laboratories operate within complex socio-epistemic contexts and are inherently transdisciplinary (Bergmann et al., 2021; Schäpke et al., 2018). The plurality of epistemic approaches inevitably leads to socio-epistemic conflicts. These conflicts can only be addressed through mechanisms that assess the quality of knowledge production (e.g., Bergmann et al., 2021) and its suitability for the intended purposes. This situation highlights the need for more direct engagement with questions of how to orient and ‘steer’ research and innovation within the experimental setting of a living lab. Furthermore, the cultural and institutional foundations for legitimizing socio-epistemic actions in living labs require critical reflection, particularly in relation to the social order within these labs (John, 2024). Living labs frequently involve interventions in people's daily lives, with potential long-term impacts on their futures. This raises important legitimacy concerns, which must be carefully considered both within the context of living labs and in the broader framework of responsible research and innovation practices. A proper governance of living labs has to take the dynamics unleashed by socio-epistemic conflicts into account.

An important aspect to consider is who initiates the living lab—that is, which actor is in the “driver’s seat” of the concrete activity (Leminen, 2013). Some living labs are company-driven, enabling real-world testing of innovations (Hyysalo et al., 2016; Von Hippel, 2005). Many others are established by local authorities to address collective problems such as climate change (Engels & Walz, 2018), or by universities, which may use their campuses for experimentation in sustainable development (Sharp & Raven, 2021).

Evidence shows that the social configuration of these labs is shaped by the initiating actor, resulting in markedly different arrangements for how citizens and stakeholders collaborate. Moreover, the forms of interaction that emerge often reflect existing power asymmetries between actors and are therefore selective in practice (John, 2024).

Against this background, an open question concerns how to design institutional processes that enable collective engagement with orientation questions and facilitate cooperation aimed at recognizing and resolving socio-epistemic conflicts in living labs. Addressing these design challenges should be a central priority in the development of living labs.

4. Living labs and their relationship with responsible research and innovation

Living Labs have provided spaces for organisational learning and experimentation, notably since the European Network of Living Labs (ENoLL) was founded in November 2006 under the Finnish Presidency of the Council of The European Union. Since 2006, the number of certified living labs has grown to over 480. ENoLL defines living labs as: “user-centred, open innovation ecosystems based on a systematic user co-creation approach, integrating research and innovation processes in real-life communities and settings” (European Network of Living Labs 2026).

This current definition of living labs captures a constitutive element of RRI, namely, to make stakeholders co-responsible and mutually responsive to each other by engaging them in an open co-creation process. Stakeholders, including citizens, may participate in co-enquiry either through practicing citizen science or by collaborating with other stakeholders. It also focusses on innovation rather than the employment of technologies. Over the last decades, the number of dedicated living labs has grown. *Urban Living Labs*, for example, are living labs which bring Quadruple Helix actors together in specific geographic areas to co-create knowledge and innovation process to bring about sustainable urban living conditions (UNaLAB, 2020, p.5). These living labs mediate social and technological solutions to inform policy and urban planning. They, thereby, take up an important feature of Responsible Innovation by defining shared goals and visions for urban futures co-created with citizens. The advantage of these dedicated urban labs is that they test solutions in real-world settings such as buildings, streets, quarters, or entire cities (UNaLAB, 2020, p.5), thereby making solutions visible. They also contribute to innovation governance as in urban settings a particular mix of technological and social innovations may converge in innovative solutions.

Hassan (2014) has elaborated on the concept of *social labs* which are dedicated to complex social problems and progressively also to the grand societal challenges, such as climate change, representing typical issues faced in responsible research and innovation. These labs are, as all other living labs, essentially experimental in nature and they have to be established as ongoing and sustained efforts and not as one-off experiments (Hassan, 2014, p.3). This is naturally the case if addressing issues of sustainability is to be taken seriously as sustainable ‘solutions’ never fixed. Impacts of preliminary envisioned solutions have to be assessed and monitored, since the nature of technological developments and their social and environmental consequences are hardly predictable. Hence the features of monitoring, foresight and shared visions for the future should be part and parcel of living labs focussing on sustainability issues

with a medium to long-term time horizon. Neuberger et al. (2024) have put these elements into practice in the EU-funded project DigiTeRRI (https://digiterri.eu/) by developing roadmaps with visions, actionable objectives and implementation plans addressing the innovation ecosystem of whole regions (e.g. Styria in Austria, Värmland in Sweden, and the Grand Est in France) and by engaging societal actors in a transformation of the innovation systems in these regions with traditional industries to a future, based on digital technologies. The project practised principles of Responsible Innovation by ensuring an open, responsive, inclusive, and anticipatory approach while co-creating the roadmaps for the future with quadruple helix actors.

The EU-funded project NewHoRRIzon (https://newhorizons-eu.org/index.html) adopted and adapted Zaid Hassan's concept of Social Labs to the policy-uptake of RRI objectives by means of quadruple helix-based pilot actions (Griessler & Blok, 2023). The project established 19 Social Labs reflecting research and innovation policy objectives of the previous EU framework Programme Horizon 2020 (European Commission, n.d.). The employment of Social Labs demonstrated to have a great potential for bottom-up policy uptake but that they also showed that "RRI needs support on the meso-level of institutions to mature single pilot activities; to anchor them in organisational rules, norms, and routines" (Griessler, Blok, 2023). Braun et al. (2023) explored the potential of Social Labs, to support learning on Responsible Research and Innovation (RRI) in standing governance organizations. They conclude that: "[a] Social Lab may turn into a learning organization, be it a temporary one. Responsibility in research and innovation is conducive for learning in the setting of a Social Lab, and Social Labs act as intermediary organizations, which not merely pass on information among actors but also actively give substantive shape to what they convey from a practice-informed, normative orientation." Here the notion of the Social Lab touches upon the most essential element of responsible innovation, namely the possibility to shape the characteristics of technologies and provide normative direction to innovation processes.

Watanabe et al. (2023) went a step further with the inclusion of 'design researchers' in the employment of a social lab to facilitate the consideration of ethical and social issues in design of digitalised technology services: "Design researchers conduct value explorations and study design services for extended values with citizens and other stakeholders such as companies and municipalities. These design practices are conducted in parallel with research and development. The design researcher communicates with or even involves researchers in sharing ideas about the values that need to be fulfilled, and the services expected. The technology is subsequently developed and integrated into the designed service." Watanabe et al. (2023) practised the inclusion of citizens in living labs to arrive at a value-driven design of digital services. The design researcher has the significant role of mediating the values of citizens and researchers while enabling also mutual learning to anticipate socially acceptable practices. The Social Lab with the inclusion of design researchers can be considered to make research and innovation value driven. This particular Social Lab of Watanabe et al. (2023) practised a 'Responsibility by Design' approach. It is important to note here that RRI principles are implemented in the research and innovation process and sustained in their outcomes (products).

Stahl et al. (2021). also recommended the employment of 'responsibility by design' based on their experiences of integrating RRI in the Human Brain Project by addressing a European Research Infrastructure as the major outcome of the Human Brain Project. Obviously, this infrastructure will exist for the medium to long-term. Stahl et al. (2021) argue that: "For RRI to become truly successful, it must be part of the research and innovation product and process and not seen as simply an external requirement/complement."

The above review of the evolution of living labs and their dedication to a particular subject matter (e.g., urban labs, social labs, and responsible living labs) reveals that living labs have progressively taking up principles of Responsible Research and Innovation in their practice.

Another approach for directing research and innovation to socially desirable outcomes is the implementation of mission-oriented research (Mazzucato, 2020). In such missions, stakeholders and citizens collaborate on open research and innovation agendas with a social commitment to a socially desirable outcome. The elements of co-creation and co-design which are often part of recently established living labs are now introduced right into the heart of research and innovation trajectories. The new EU framework programme has introduced mission-oriented research (with targets that are essentially social, not only scientific-technological) as a means for fostering innovation by co-design and co-creation towards democratically decided main objectives (e.g., as a result of deliberation among stakeholders, the member states of the EU and the European Parliament). The missions will also all have to feature an essential input from citizens, including citizen science practices. The missions on 'Healthy Soil' and 'Smart Cities' employ dedicated living labs to advance these missions.

However, Wiarda et al. (2024) rightly note that "these missions require a 'responsible mission governance' which should integrate various complementary governance responsibilities relating both to epistemic issues and normative issues to potentially improve the effectiveness and desirability of missions. They point to the complexity of the societal challenges which are the subject matter of the missions and their inherent scientific uncertainties and conflicting epistemic approaches which make them 'wicked.' Von Schomberg (1992) argued that social cooperation among stakeholders both on normative issues and on the epistemic issues accompanying mission-oriented research promotes consensus-building on problem definitions and the problem-solving capacities we intend to employ. On one hand, this can neutralize scientific dissent, for the duration of the missions, which often arises due to discipline-specific approaches and implicit problem framings (von Schomberg, 1992). On the other hand, it can overcome one-sided problem definitions prevalent in public policy settings. For example, climate change policy historically emphasized climate mitigation strategies while neglecting climate adaptation strategies (Stehr & Von Storch, 2023). The missions flag, however, the necessity to make transformative changes possible and should comprise compensation for the fact that markets do not deliver on transformative changes without governmental intervention and governance. This is an additional important reason to have living labs feature in the context of missions. As noted, issues of sustainability in its comprehensive form, which includes the mutually dependent relationships of social, economic, and environmental dimensions, require foresight, monitoring, and experimentation. Coffay et al. (2022) rightly state that 'when innovation is intentionally linked with a sustainability mission, even greater focus is needed on exploration and experimentation', effectively making the case that forecasting, and assessment of sustainability gains are intertwined. However, their notion of 'forecasting' is better understood as foresight based on various plausible scenarios for the future rather than on pure predictions. This is more appropriate given the uncertain nature of technological development and their social consequences. Crucially, foresight and assessment and the implementation of RRI is dependent on the context-specific input of knowledge and innovation actors.

There is a significant gap in the RRI literature which has focussed on RTD trajectories rather than on the effectuation of innovation processes in practice. It also has practically ignored the specifics of the entrepreneurial sciences and practices for innovation. Coffay et al. (2022) provide an original attempt on how: "Forecasting and assessment can be framed in an RRI context while incorporating aspects of effectuation theory via a Responsible Innovation Lab (RIL)." This lab is still understood as a particular type of living lab, originally conceptualised by William Mitchell at MIT as a "research methodology for sensing, prototyping, validating and refining complex solutions in multiple and evolving real life contexts" (Eriksson et al., 2006). Habibipour (2024) also proposed a 'Responsible living lab' based on a review of literature of both RRI and living labs and makes it fruitful for AI-driven digital transformation processes. He defines responsible living labs as frameworks that ensure transparency, stakeholder engagement, ethical

considerations, and sustainability. The Responsible living lab ensures inclusivity, ethical considerations, and sustainability throughout all stages of the innovation process, helping researchers and practitioners conduct AI-enabled digital transformation processes responsibly and ethically. Parodi et al. (2022) propose 'Reflexive Sustainable Technology Labs' as transformative experimental settings that combine elements of Technology Assessment (TA), Responsible Research and Innovation (RRI), and real-world laboratories. While their contribution offers a valuable conceptual synthesis, it engages only to a limited extent with the practical implications of anticipatory governance as they arise in concrete research and innovation processes. In particular, the approach treats the underlying logics of TA, RRI, and real-world laboratories as largely additive and thus readily combinable within a single lab format. By contrast, the RRI Lab concept developed here places greater emphasis on the tensions, trade-offs, and reflexive work required to navigate these logics in practice, rather than assuming their synthesis leads to a straightforward increase in rationality.

4.1. Essential features of RRI-Labs

The above analysis and review of dedicated Living Labs showed that all Living Labs as defined by ENoLL (2026) share the essential RRI feature of *making stakeholders co-responsible and mutually responsive to each other by engaging them in an open co-creation/co-enquiry process.* Dedicated living labs have demonstrated to have the following features which underpin RRI (Table 1 summarises the RRI features of the distinct living labs and their contribution to institutional change of RRI):

4.2. Urban livinglabsdefine shared goals and visions for urban futures co-created with citizens

Social Living Labs feature an open, responsive, inclusive, and anticipatory approach. They can function as an intermediary learning organisation to provide a normative orientation and fostering organisational change. This normative orientation can go beyond organisational change to tackle major societal challenges.

Responsible Design can be integrated into living labs to foster value-driven research and innovation. This relates to the innovation process and is sustained in the desirable outcomes and products.

Participative Foresight can contribute to the transformative change of whole regions by articulating shared visions, values for regional change.

Societal challenge-based mission-oriented Research and Innovation integrates the RRI feature of directing research and innovation towards socially desirable ends by taking co-creation and co-design as modus operandi of research. Living Labs currently provide capacity to particular missions under the EU Framework Programme for Research and Innovation.

Living labs thus provide a research and innovation infrastructure that responds to the call for institutional change by Von Schomberg et al. (2023):

- Innovation must be value-driven.
- Implementation of an ethics of co-responsibility among stakeholders.
- Innovation should be made directional and manageable.
- Market failures need to be addressed to facilitate necessary transformative changes, especially regarding the Sustainable Development Goals.

Table 1
Overview of types of Living Labs and their specific contribution to institutional change for RRI.

Type of Living Lab	Specific conceptual contribution to RRI	Corresponding institutional change for RRI
All Living Labs	Making stakeholders co-responsible and mutually responsive to each other	Ethics of co-responsibility
Urban Living labs	Co-creation of collective visions for the future	Making innovation directional and value driven
Social Living Labs	Addressing societal challenges, fostering change through organizational learning	Making innovation directional and value driven
Living Labs supporting societal challenge-based mission-oriented research and innovation	Making research and innovation directional to socially desirable ends	Addressing market-failures Enabling Transformative change in relation to Sustainable Development Goals
Responsible Research and Innovation Labs for Engineering Practices	Responsible value-sensitive Design of technologies Ecosystem approach with participative foresight and open innovation, enabling anticipatory governance	Aligning technologies with public values in engineering contexts Render the entire innovation ecosystem value-driven and oriented towards socially desirable ends

5. Towards a conceptualization of RRI-Labs for engineering practices

To grasp the challenges of implementing Responsible Research and Innovation (RRI) within a living lab tailored to entrepreneurial science and engineering, it is essential to understand how engineering differs from traditional natural sciences. Engineering is inherently design-oriented: scientists anticipate physical and social consequences long before products appear, exemplified by notions like *"safety by design"* in the nanosciences or *"privacy by design"* in computer science. This mindset internalizes responsibility within the scientific process: once you create or design, you are accountable for the outcomes. The long-standing practice of diverting responsibility to politics or industry—once endorsed by academies of science—is untenable for the modern engineer. Whereas pure science has traditionally been remote from issues of responsibility for the societal outcomes of the sciences, engineering has to embrace the ethos of responsible creation and design.

Engineering naturally aligns with RRI's value-driven agenda, embedding societal values directly into technological design. Yet, a tension persists: engineering often resists open-innovation models (and focus on patenting possibilities instead) that emphasize shared knowledge and collective development. Schiuma and Santarsiero (2024) propose open innovation labs that function as organizational catalysts across an organization and its ecosystem and includes business-model innovation. Yochai Benkler (2017) highlights the tension between proprietary approaches and open innovation models. He observes a shift from lone inventors (e.g., Steve Jobs, creating the first personal computer in his garage) toward collaborative networks—firms, universities, and individuals—sharing knowledge to accelerate innovation. In this paradigm, innovation emerges from communal knowledge flows, making traditional levers like patents potentially counterproductive (Lemley, 2012). Benkler also notes a broader shift away from purely market-driven innovation toward socially motivated or publicly funded innovation networks. These networks can foster socially beneficial innovation—aligned with RRI—by emphasizing public investment and collective learning over firm-centric competition.

Engineering practices are well-suited to embrace responsible design—but this requires navigating the tension between proprietary, firm-based innovation and open, networked collaboration. The goal is to cultivate innovation ecosystems, rather than isolated inventions. For example, Zaratin et al. (2022) designed a holistic RRI governance framework in brain health research, incorporating multi-actor collaboration and patient engagement. Campos and Marín-González (2023) established twelve renewable energy living labs across Europe. Metta et al. (2022) embedded RRI into twenty-one agricultural digitalization

labs.

Governments increasingly support system-level innovation, acknowledging that conventional markets often fail to deliver timely, sustainable, and equitable transformations. Achieving this requires governance redesign—not just enabling change but actively guiding it. RRI-Labs can serve this role by mobilizing ecosystem actors and fostering mutual responsiveness toward shared societal goals.

Targeted engineering domains—whether additive manufacturing, hydraulic engineering, digital innovation, or other fields of engineering—RRI-Labs tailored for these specific engineering practices could offer open, value-aligned platforms. They could empower all actors within the quadruple helix to co-create research and innovation pathways that are socially and ethically grounded. Such labs would provide anticipatory governance by proactively steering innovation toward socially desirable outcomes.

RRI-Labs tailored to engineering practices could also play a pivotal role in advancing the development and implementation of Artificial Intelligence (AI). The current EU legislative framework for AI—embodied in the *AI Act*—is widely regarded as a pioneering effort to address the risks associated with the innovative outcomes of AI technologies while upholding the market principle of technological neutrality. However, this framework fails to consider the growing dependency on AI systems whose operational mechanisms often remain opaque, frequently protected by private intellectual property rights. Although the Act promotes compliance with ethical standards—such as the respect for individual autonomy—it falls short of articulating what constitutes *socially desirable* outcomes. At this point, the ambition of RRI goes beyond that of ethics. RRI introduces a socio-political dimension: it not only seeks to respect human agency but to *enhance* it through public investment in AI systems designed to serve the public good.

For instance, public investment in AI for healthcare could help steer technological development toward socially desirable goals, rather than leaving public health systems dependent on market-driven operators who supply narrowly defined tools. In this context, RRI-Labs dedicated to (public) AI development could bring together healthcare professionals, patients, hospitals, AI developers and other stakeholders to co-develop and implement socially beneficial, AI-mediated technologies—such as telemedicine platforms—that improve access to care for patients living in remote regions.

Based on the above review of essential features of Living Labs in terms of their contribution to responsible innovation, the following key features emerge for responsible innovation labs for engineering practices:

1. Mission-orientation: Embed co-design and co-creation to support targeted societal goals—e.g., smart cities, sustainable development goals.
2. Institutional capacity-building: Encourage organizational learning, identify barriers and drivers for open, responsible research and innovation practices.
3. Experimentation and foresight: Combine real-world experimentation with scenario planning and monitor progress.
4. Knowledge sharing incentives: Early knowledge and data sharing, open collaboration, and transparency.
5. Mediation of socio-technical change: Facilitate stakeholder alignment on common outcomes.
6. Adaptive governance: Support organizational transformation within partner institutions and contribute to policy adaptation.
7. Societal direction: Use mission-based research frameworks to align projects with normative goals.
8. Transformative impact: Orchestrate innovation within defined ecosystem-level or territorial (e.g., regional, national) objectives (for example, climate objectives within the Green Deal).
9. Engineering specificity: Enable responsible creation (value sensitive) /design of technologies with embedded values.
10. Context-sensitivity: Ground research and innovation activities in their specific social, institutional, cultural, and regulatory contexts, recognizing that responsible outcomes depend on locally situated conditions, constraints, and stakeholder configurations.
11. Networked learning: Foster interactions between technology producers and users for communal learning and public benefit.

An RRI-Lab for engineering practices would thus operate as a mission-driven, collaborative space where engineers and all stakeholders, including societal actors, co-design solutions aligned with contextually specified overarching goals, such as sustainability, public welfare, and social/societal wellbeing. An RRI-Lab should therefore be a place enabling reflexivity in knowledge acquisition through appropriate stakeholder participation design. It would build institutional capacity for responsible innovation by fostering organizational learning, early knowledge sharing, and open data practices. Through scenario planning, real-world experimentation, and adaptive governance, the lab would enable continuous reflection, alignment, and policy-relevant insights. By embedding values into technology design and supporting structured socio-technical mediation, the lab would drive transformative, ecosystem-level change while cultivating networked learning across communities of practice.

CRediT authorship contribution statement

René von Schomberg: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Stefan Böschen:** Writing – original draft, Investigation, Formal analysis, Conceptualization. **Julia Backhaus:** Investigation, Formal analysis, Conceptualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Alavi, H. S., Lalanne, D., & Rogers, Y. (2020). The five strands of living lab: A literature study of the evolution of living lab concepts in HCI. *ACM Transactions on Computer-Human Interaction, 27*(2), 1–26. https://doi.org/10.1145/3380958

Augenstein, K., Levin-Keitel, M., Trenks, H., & Bögel, P. M. (2022). Wie entfalten Reallabore Wirkung für die transformation? Eine embedded-agency-perspektive zur analyse von wirkmechanismen in Reallaboren. *GAIA – Ecological Perspectives for Science and Society, 31*(4), 207–214.

Backhaus, J., John, S., Böschen, S., dela Varga, A., & Gramelsberger, G. (2022). Reallabore um die RWTH Aachen: Rückblicke, Einblicke, Lichtblicke. *Pnd – Planung Neu Denken, 1*(2022). https://doi.org/10.18154/RWTH-2022-05170

Backhaus, J., & John, S. (2025). Generalization as local and translocal embedding: Interrogating governance and deconstructing democratization in living labs. *Sustainability: Science, Practice and Policy, 21*(1). https://doi.org/10.1080/15487733.2025.2450856

Benkler, Y. (2017). Peer production, the commons, and the future of the firm. *Strategic Organization, 15*(2), 264–274.

Bergmann, M., Schäpke, N., Marg, O., Stelzer, F., Lang, D. J., Bossert, M., Gantert, M., et al. (2021). Transdisciplinary sustainability research in real-world labs: Success factors and methods for change. *Sustainability Science, 16*, 541–564. https://doi.org/10.1007/s11625-020-00886-8

Borras, S., & Edler, J. (2014). The governance of change in socio-technical and innovation systems: Three pillars for a conceptual framework. *Social and political science* (pp. 23–48). Edward Elgar. https://doi.org/10.4337/9781784710194

Braun, R., Loeber, A., Vinther Christensen, M., Cohen, J., Frankus, E., Griessler, E., Hönigmayer, H., & Starkbaum, J. (2023). Social labs as temporary intermediary learning organizations to help implement complex normative policies: The case of responsible research and innovation in European science governance. *The Learning Organization, 30*(6), 713–739. https://doi.org/10.1108/TLO-09-2021-0118

Campos, I., & Marín-González, E. (2023). Renewable energy living labs through the lenses of responsible innovation: Building an inclusive, reflexive, and sustainable energy transition. *Journal of Responsible Innovation, 10*(1). https://doi.org/10.1080/23299460.2023.2213145

Carayannis, E. G., & Campbell, D. F. J. (2009). Mode 3 and quadruple helix: Toward a 21st-century fractal innovation ecosystem. *International Journal of Technology Management, 46*(3–4), 201–234. https://doi.org/10.1504/IJTM.2009.023374

Coffay, M., Coenen, L., & Tveterås, R. (2022). Effectuated sustainability: Responsible innovation labs for impact forecasting and assessment. *Journal of Cleaner Production, 376*, Article 134324. https://doi.org/10.1016/j.jclepro.2022.134324. Article.

Compagnucci, L., Spigarelli, F., Coelho, J., & Duarte, C. (2021). Living labs and user engagement for innovation and sustainability. *Journal of Cleaner Production, 289*, Article 125721. https://doi.org/10.1016/j.jclepro.2020.125721. Article.

Engels, A., & Walz, K. (2018). Dealing with multi-perspectivity in real-world laboratories. *GAIA – Ecological Perspectives for Science and Society,* 27(1), 39–45. https://doi.org/10.14512/gaia.27.S1.10.

Engels, F., Wentland, A., & Pfotenhauer, S. (2019). Testing future societies? Developing a framework for test beds and living labs as instruments of innovation governance. *Research Policy, 48*(9), Article 103826. https://doi.org/10.1016/j.respol.2019.103826

Eriksson, M., Niitamo, V.-P., Kulkki, S., & Hribernik, K. A. (2006). Living labs as a multi-contextual R&D methodology. In *Proceedings of the IEEE International Technology Management Conference* (pp. 1–8). https://doi.org/10.1109/ICE.2006.7477082

European Commission. (2019). *The European Green Deal*. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/story-von-der-leyen-commission/european-green-deal_en.

European Commission. (2021). *Horizon Europe strategic plan 2021-2024*. Publications Office of the European Union. https://data.europa.eu/doi/10.2777/083753.

European Commission. (n.d.). Horizon 2020. https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-2020_en.

European Network of Living Labs. (2026). *About us*. https://enoll.org/about-us.

Forsberg, E.-M., & Wittrock, C. (2023). The potential for learning from good RRI practices. *The Learning Organization, 30*(6), 687–712.

Ghosh, B., Kivimaa, P., Ramirez, M., Schot, J., & Torrens, J. (2021). Transformative outcomes: Assessing and reorienting experimentation with transformative innovation policy. *Science and Public Policy, 48*(5), 739–756. https://doi.org/10.1093/scipol/scab045

Griessler, E., & Blok, V. (2023). Conclusion: Implementation of responsible research and innovation by social labs: Lessons from the micro-, meso-, and macro perspective. Ed.. In V. Blok (Ed.), *Putting responsible research and innovation into practice: 40. Putting responsible research and innovation into practice*. Springer. https://doi.org/10.1007/978-3-031-14710-4_14

Grunwald, A. (2018). *Technology assessment in practice and theory*. Routledge.

Guston, D. H. (2014). Understanding anticipatory governance. *Social Studies of Science, 44*(2), 218–242.

Habibipour, A. (2024). Responsible living labs: What can go wrong? *Journal of Information, Communication and Ethics in Society, 22*(2).

Hassan, Z. (2014). *The social labs revolution*. Berrett-Koehler.

Hennen, L. (2012). Why do we still need participatory technology assessment? *Poiesis & Praxis, 9*, 27–41. https://doi.org/10.1007/s10202-012-0122-5

Hossain, M., Leminen, S., & Westerlund, M. (2019). A systematic review of living lab literature. *Journal of Cleaner Production, 213*, 976–988. https://doi.org/10.1016/j.jclepro.2018.12.257

Hyysalo, S., Jensen, T. E., & Oudshoorn, N. (2016). *The new production of users*. Routledge.

Hyysalo, S., & Johnson, M. (2024). Making sense of methods and approaches to user involvement. *Design Journal, 27*(4), 580–608. https://doi.org/10.1080/14606925.2024.2347736

John, S. (2024). Living labs: Knowledge infrastructures to forge a new social contract of science? *Journal of Innovation Management, 12*(3), 75–100. https://doi.org/10.24840/2183-0606_012.003_0011

Leminen, S. (2013). Coordination and participation in living lab networks. *Technology Innovation Management Review, 3*(11), 5–14. https://doi.org/10.22215/timreview/740

Lemley, M. A. (2012). The myth of the sole inventor. *Michigan Law Review, 110*(5), 709–760. https://repository.law.umich.edu/mlr/vol110/iss5/1.

Marchi, G., Giachetti, P., & De Gennaro, P. (2011). Extending lead-user theory to online brand communities: The case of the community Ducati. *Technovation, 31*(8), 350–361. https://doi.org/10.1016/j.technovation.2011.04.004

Metta, M., Ciliberti, S., Obi, C., Bartolini, F., Klerkx, L., & Brunori, G. (2022). An integrated socio-cyber-physical system framework to assess responsible digitalisation in agriculture: A first application with living labs in Europe. *Agricultural Systems, 203*, Article 103533. https://doi.org/10.1016/j.agsy.2022.103533. Article.

Mazzucato, M., Kattel, R., & Ryan-Collins, J. (2020). Challenge-driven innovation policy: Towards a new policy toolkit. *Journal of Industrial Competitiveness and Trade, 20*, 421–437. https://doi.org/10.1007/s10842-019-00329-w

Nordmann, A. (2019). The ties that bind: Collective experimentation and participatory design as paradigms for responsible innovation. Eds.. In R. von Schomberg, & J. Hankins (Eds.), *International handbook on responsible innovation: A global resource* (pp. 181–193). Edward Elgar

Neuberger, S., Paier, M., & Hörlesberger, M. (2024). The effects of RRI-oriented roadmapping on the digital transformation of regions. *Journal of Responsible Innovation, 11*(1). https://doi.org/10.1080/23299460.2024.2414519

Owen, R., von Schomberg, R., & Macnaghten, P. (2021). An unfinished journey? Reflections on a decade of responsible research and innovation. *Journal of Responsible Innovation, 8*(2), 217–233. https://doi.org/10.1080/23299460.2021.1948789

Pallot, M., Trousse, B., Senach, B., & Scapin, D. (2010, August). Living lab research landscape: From user centred design and user experience towards user cocreation. Paper presented at the First European Summer School "Living Labs," Inria (ICT Usage Lab), Userlab, EsoceNet, Universcience, Paris, France.

Parodi, O., Bögel, P., Beecroft, R., Seebacher, A., Wagner, F., & Hahn, J. (2022). Reflexive sustainable technology labs: Combining real-world labs, technology assessment, and responsible research and innovation. *Sustainability, 14*(22), Article 15094. https://doi.org/10.3390/su142215094. Article.

Schäpke, N., Stelzer, F., Caniglia, G., & Bergmann, M. (2018). Jointly experimenting for transformation? Shaping real-world laboratories by comparing them. *GAIA, 27*(1), 85–96.

Schneidewind, U., Augenstein, K., Stelzer, F., & Wanner, M. (2018). Structure matters: Real-world laboratories as a new type of large-scale research infrastructure. *GAIA, 27*(S1), 12–17.

Schiuma, G., & Santarsiero, F. (2024). *Open innovation labs: Unlocking organizational innovation capacity*. Springer. https://doi.org/10.1007/978-3-031-75533-0

Schuurman, D., & Protic, S. (2018). Living labs versus lean startups: An empirical investigation. *Technology Innovation Management Review, 8*(12), 7–16. https://doi.org/10.22215/timreview/1201

Sharp, D., & Raven, R. (2021). Urban planning by experiment at precinct scale: Embracing complexity, ambiguity, and multiplicity. *Urban Planning, 6*(1), 195–207. https://doi.org/10.17645/up.v6i1.3525

Stahl, B. C., Akintoye, S., Bitsch, L., Bringedal, B., Eke, D., Farisco, M., & Ulnicane, I. (2021). From responsible research and innovation to responsibility by design. *Journal of Responsible Innovation, 8*(2), 175–198. https://doi.org/10.1080/23299460.2021.1955613

Steer, N., & von Storch, H. (2023). *Die wissenschaft in der gesellschaft: Klima, klimawandel und klimapolitik*. Springer. https://doi.org/10.1007/978-3-658-41882-3

UNaLAB. (2020). *Living lab handbook for urban living labs developing nature-based solutions*. https://unalab.eu/system/files/2020-07/living-lab-handbook2020-07-09.pdf.

Von Hippel, E. A. (2005). *Democratizing innovation*. MIT Press.

Von Schomberg, R. (2013). A vision of responsible innovation. In R. Owen, M. Heintz, & J. Bessant (Eds.), *Responsible innovation: Managing the responsible emergence of science and innovation in society (pp. xx–xx)*. John Wiley.

Von Schomberg, R. (1992). Controversies and political decision making. Ed.. In R. von Schomberg (Ed.), *Science, politics, and morality: Scientific uncertainty and decision making* (pp. 7–26). Springer

Von Schomberg, R. (2019). Why responsible innovation. In R. von Schomberg, & J. Hankins (Eds.), *International handbook on responsible innovation: A global resource* (pp. 12–32). Edward Elgar.

Von Schomberg, L., & Von Schomberg, R. (2023). Responsible innovation as a social innovation. In J. Howaldt, & C. Kaletka (Eds.), *Encyclopedia of social innovation*. Edward Elgar.

Wanner, M., Hilger, A., Westerkowski, J., Rose, M., Stelzer, F., & Schäpke, N. (2018). Towards a cyclical concept of real-world laboratories: A transdisciplinary research practice for sustainability transitions. *DisP – The Planning Review, 54*(2), 94–114.

Wanner, M., Augenstein, K., von Wirth, T., & Lang, D. (2024). Impacts of urban real-world labs. *GAIA, 33*(1), 102–109.

Watanabe, K., Akasaki, F., Mitake, Y., & Kojima, K. (2023). Social lab: Toward value-driven R&D&I in collaboration with citizens. https://doi.org/10.3384/ecp203063.

Wiarda, M. J., Janssen, T. B. J., Coenen, T., & Doorn, N. (2024). Responsible mission governance: An integrative framework and research agenda. *Environmental Innovation and Societal Transitions, 50*, Article 100820. https://doi.org/10.1016/j.eist.2024.100820

Zaratin, P., Bertorello, D., Guglielmino, R., Devigili, D., Brichetto, G., Tageo, V., Dati, G., Kramer, S., Battaglia, M. A., & Di Luca, M. (2022). The MULTI-ACT model: The path forward for participatory and anticipatory governance in health research and care. *Health Research Policy and Systems, 20*(1), 1. Article.

Zukunft, Quartier (2020). *Dein quartier und du – nachhaltigkeitsexperimente im reallabor zu nachbarschaften, bienen, naschbeeten*. Kreativität und Konsum. Scientific Publishing.