Article

JIM
ISSN: 2183-0606
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Vol. 12, 3 (2024)
p. 226-250
AM: Jun/2024
SM: Aug/2023

Situated Living Labs: Multi-level Theoretical Foundations with Illustrative Case Examples

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Abstract

Living labs have been utilised to help address a diverse range of complex societal issues, but individual instances are situated in a particular time-place-problem context. Previous studies had suggested a need for theory-based reference models to support the framing of living lab operations. The aim of this conceptual paper is to draw on established practitioner and academic experience to match key concepts with an innovative Socio-Technical-System product model and a Cultural-Historical Activity Theory process model adapted for this purpose. Multiple living lab explanatory case studies are used to illustrate the application of the concepts presented and to outline socioeconomic ecosystem linkages with subsidiary innovation, business and knowledge ecosystems. The important contribution of living lab stakeholder experiential learning and impact assessment is noted, and we offer suggestions for future research on these subjects.

Keywords: living labs, open innovation, diffusion of innovation, knowledge management, socio-technical systems, activity theory, experiential learning.

Cite paper as: Beckett, R.C., O'Loughlin, A. M., (2024). Situated Living Labs: Multi-level Theoretical Foundations with Illustrative Case Examples, *Journal of Innovation Management*, 12(3), 226-250.; DOI: https://doi.org/10.24840/2183-0606_012.003_0010

1 Introduction

This conceptual paper was stimulated by a journal special edition call for papers that further develop the conceptual and theoretical foundations of living labs. Hossain et al (2019) had suggested: (p986) "future studies could explore various types of open innovation activities that are performed in different situations", and that - "Stakeholders wishing to set up a living lab and its activities, as well as firms considering developing one, find limited reference models for developing and managing a living lab. Soini et al (2023) suggested that the influence of context on co-creation processes is insufficiently recognized, particularly when considering nature-based solutions and discussed the value of a relational place-based approach in living labs. They suggested the co-creation process should be viewed as a 'dynamic confluence of many interconnections'. Greve et al (2020) examined living lab research directions in a bibliometric study. They suggested there were opportunities to consider previously unused theoretical approaches in taking a cross-disciplinary perspective.

In this paper we take up these challenges, proposing reference models utilised in other settings and consider two research questions: (a) how may different modes of user engagement be associated with particular kinds of innovation activities, and (b) how may proposed reference models be used to characterise living lab context and operations.

The term 'living lab' has been characterised as an approach or methodology for collaborative innovation, as an arena or environment in which the innovation activities take place, or a broader ecosystem or open innovation network, among other interpretations (McPhee et al, 2021). Living labs are seen as situated within a system of innovation at a macro-level, and in an open innovation context at a micro-level (Amirall and Wareham, 2008). They have been utilised to help address a diverse range of complex societal issues, but individual instances are situated in a particular time-place-problem context. Temporal factors may be viewed in terms of emergent trends, life-cycle stages and windows of opportunity (e.g., in the adoption of digital technologies and funding access windows). We view place attributes in terms of the socioeconomic ecosystem and it's embedded culture that a living lab draws on and contributes to (e.g., urban or rural living labs). Problem context is characterised in terms of the type of innovative socio-technical system being established to help facilitate transformational change.

The authors reflected on several decades of personal experience with different kinds of Australian cross-disciplinary ventures (e.g., cooperative research centres and industry clusters). Reference models found useful in those settings were considered as candidates in a living lab setting. We observed two recurring themes in our prior experience that may be applied in a living lab context. Firstly, adapted reference models aid in sense-making, in facilitating innovation development and deployment, and in developing protocols to support those adversely impacted by change. Reference models may also facilitate buy-in by indicating a way forward in an environment of uncertainty. Secondly, desired transformational outcomes need to be mapped in a structured way, framing context by cooperatively addressing concerns and deciding what practices need to be retained and what needs to change.

The paper starts by considering living lab practitioner experience accumulated over more than 15 years by ENoLL (European Network of Living Labs) members, then draws on multiple viewpoints from the literature and introduces models to frame context that illustrate the complex array of interactions to be considered. We present a systems architecture model, a socio-technical systems model to consider different open innovation development scenarios and an adapted activity system reference model drawing on Cultural-Historical Activity Theory. These models have been utilised in other applications, but rarely in a living lab context.

The application of the models identified is illustrated in five Australian cases, and we discuss implications for practitioner utilisation of living labs as a strategic tool.

2 Related Work and Theoretical Perspectives

We briefly reviewed both practical experience (e.g., as represented in ENoLL documents) and the academic literature to investigate the questions referred to earlier. Data items accumulated from multiple keyword searches were stored in a commercial library repository (https://c-command.com/eaglefiler/) that supported search through multimedia data types. Notes could be associated with each data item and items related to a particular theme could be tagged. The initial set of tags introduced were multi-level, co-creation, stakeholders, experimentation, and ecosystem. More tags were added (e.g. learning, impact) as we accumulated references. Tags could be organised in hierarchies e.g., nesting innovation, business and knowledge ecosystem under the ecosystem umbrella term. The same system was used for collecting and analysing our case material. At the time of writing 247 data items had been included (26 providing case study material) . We selected references cited in this paper on the basis that they consolidated past experience (e.g., drawing on comprehensive literature surveys) or were widely cited or described current thinking.

2.1 Some Living Lab practitioner perspectives

ENoLL was founded as a community of practice in 2006 with 20 registered members increasing over the following 15 years to more than 460 registered living labs. Living Labs are defined as *real-life test and experimentation environments that foster co-creation and open innovation among the main actors of the Quadruple Helix Model, namely citizens, government, industry and academia*. A timeline of key events showed progressive engagement outside the European Union. Ten special interest working groups are being supported, indicating the breadth of living lab application fields (problem space) being explored (ENoLL 2023). Every few years ENoLL publishes a document showcasing the activities of a number of new members. We drew on this data over the period 2018 - 2020 to gain some insight into the scope of activities covered in some 50 cases. In most cases measures of success were formalised to facilitate post-program assessment of performance. Some cases were strongly oriented towards social change and some towards technology adoption, but most pursued some combination of the two. Each year ENoLL publishes a member list and an analysis of the collective areas of work being undertaken (20 areas noted) and living lab type (urban, rural, testbed, research, living lab as a service). The strongest member orientations were towards research living labs (74%) and the operation of living labs as an innovation intermediary service (59%), also recognising that some living labs may have multiple orientations (51% urban living labs, 43% providing a living testbed). Some ENoLL member project groups have reflected on their experience with the establishment and operation of living labs and offered advice to others relating to practice and challenges via on-line handbooks. We scanned the contents of four handbooks finding that, in general, guidance was provided in relation to themes such as co-creation and stakeholder engagement. These handbooks provide a means of *learning for* LL engagement (education) and evidence of *learning from* LL engagement (reflexivity, e.g., Bruno et al, 2011). One approach to learning and knowledge sharing across boundaries was the use of pattern language cards (e.g., Akasaka et al, 2020) and this may be a topic of further research.

2.2 Some Living Lab academic perspectives

Whilst we assembled a library of references, in the following we draw on a widely cited living lab literature review by Hossain et al (2019) to characterise living lab attributes which we summarised as follows:

- Living labs are established to help meet complex societal challenges and introduce sustainable transformational change outcomes. Individual instances may be oriented towards a particular kind of innovation (e.g. service, social or technological innovation)
- Living lab activities utilise a form of experimentation in real-life environments where innovation and learning processes are explicitly specified to facilitate mutual understandings of society's technical requirements and the social impacts of innovation via an iterative process over time that also facilitates technology transfer.
- Living labs act as intermediaries, spanning boundaries between developers and users with support from other intermediaries, business and institutional actors
- A value proposition element of a business model may difficult to communicate as different stakeholders may have different expectations. Because many living labs operate through project-based funding, they may only be established for the life of a project and there may be some difficulty if ongoing operation is appropriate. The role of technology may be understood as a resource associated with value creation and appropriation.
- There is a heterogeneous mix of stakeholders that may play different roles at different times, e.g. academics, students, developers, industry representatives, citizens, users, and various

public and private non-profit organizations. These actors may play generic roles as enablers (making it all possible), providers (development actors), users (citizens or end customers), and utilizers (other beneficiaries of innovation activities).
- Living lab engagement with multiple interacting stakeholders and operations may be viewed as networks or ecosystems where there may be a dynamic interplay between actors, activities and resources (knowledge, management tools, facilities / infrastructure).
- Living labs may face their own challenges in terms of temporality (e.g. short term or long term focus, time window availability of resources), governance (working across boundaries), unforeseen outcomes (non-achievement of goals, identification of alternative opportunities), efficiency (in the retention of learning and knowledge), the recruitment of user group(s) and the sustainability and scalability of their innovation activities.

What we take from the introduction and the foregoing is that firstly, context matters (e.g., Soini et al, 2023) and needs to be considered at multiple levels of analysis. Secondly, that multiple contributions need to be orchestrated for effective operation. These include: (a) the application environment, (b) users and providers of a proposed solution, and (c) technology and infrastructure integrated via organisation and methods (Bergvall-Kareborn et al, 2009). In other words, who does what, where, when and how.

2.3 Living lab Context (1): A regional socio-economic ecosystem intervention actor

Living labs have been characterized as an intermediary service actor that may play a variety of boundary-spanning roles such as architect, facilitator, broker (e.g. Johansson et al, 2011) within an innovation milieu (e.g., Bergvall-Kareborn et al, 2009). The term 'ecosystem' has been used to characterize living lab internal and external spaces, which may provide resources or be a beneficiary of value created through living lab operations (e.g., Äyväri and Jyrämä, 2017).

Living labs help orchestrate networks of actors, activities and resources, making different connections at different times (e.g., experimenting with ideas, testing prototypes, Nyström et al, 2014) in the pursuit of a place-based goal. That place may be viewed as a socioeconomic ecosystem where particular kinds connections may be made for specific purposes, leading to notions of a subsidiary ecosystem that supports the pursuit of innovation (e.g. de Vasconcelos Gomes et al, 2018) or business (e.g., Peltoniemi and Vuori, 2004) or knowledge-sharing (e.g., Jucevičius, 2022).

The living lab innovation ecosystem has been represented as an interactive environment following a 'quadruple helix' evolutionary pathway. Particular instance attributes depend on the nature of the leading innovation champion: academia, business, government or community actors (e.g., Arnkil et al, 2010, Beaudoin et al, 2022). The innovation and learning capabilities and orientation of each class of actor may vary from region to region. Dedehayir et al (2018) identified four generic roles facilitating the operation of an innovation ecosystem characterised as innovation leadership, direct value creation, value creation support and entrepreneurial actor. They suggested an innovation champion role would be pivotal.

de Vasconcelos Gomes et al (2018) observed that whilst a business ecosystem may focus on value capture, the focus of an innovation ecosystem is on value creation. However what is valued may vary, depending on the innovation goal (e.g., social innovation or technological innovation). Roundy et al (2018) adopted a complexity-based definition of a business ecosystem as 'A self-organised, adaptive, geographically based community of complex actors operating at multiple aggregation levels whose non-linear interactions result in patterns of activities through which new ventures form and dissolve over time'. The point to be reiterated here is that actors both draw on and contribute to the evolution of the ecosystem(s) they are embedded in.

Konno and Schillaci (2021) argue that "Today's innovation demands socio-economic fusion that goes beyond current corporate boundaries. By preparing the system (knowledge ecosystem) as the basis, we could build the bridge, and such fusion would be possible" (p478). They viewed living labs as an important actor in that process.

In summary we propose that within the socio-economic ecosystem it is embedded in, a living lab has:

- an engagement with a regional innovation ecosystem in creating value, moderated by the particular living lab goal
- an engagement with a regional business ecosystem, both drawing on resources to support living lab activities and helping to capture value for the participants.
- an engagement with a regional knowledge ecosystem to both support the living lab goal and contribute to knowledge creation and diffusion.

2.4 Living lab context (2): Mapping Living Lab systemic attributes

Living labs have an activity focus supporting specific kinds of learning modalities (experimentation and testing) and operational tasks. In the following we view living lab operations as a systematic process and adopt a systems thinking approach (Cosgrave et al, 2013, Molnar et al, 2023). Drawing on an extensive literature review, Arnold and Wade (2015) defined systems thinking as "a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects. These skills work together as a system" (p 675).

We start by using a system architecture description standard (ISO 42010: 2022) as an analytic tool to map the observations made in the literature. One of the authors has used earlier versions of this tool for number of years in teaching engineering Masters students how to characterise complex socio-technical systems and to consider ways of assessing the impact of changes to them. ISO 42010 brings together consideration of system context, functional requirements and stakeholder perspectives. The generic map is shown in figure 1, followed by an elaboration on some of the system architecture elements.

Stakeholder perspectives may be informed by three inputs: (a) consideration of options suggested by models (e.g., simulations or prior experience), community concerns, and a blending of multiple perspectives (views and viewpoints). We interpret the work of Lehmann et al (2015) framing a Living Lab as a knowledge system as a practical example. They described combining the viewpoints of activist, user and professional actors in a variety of experiential learning opportunities (views). The ENoLL living lab handbooks included advice on challenges (concerns), suggest specific administration functionality (e.g., identifying key stakeholders and keeping them motivated).

2.5 Living Lab Context (3): facilitating Socio-Technical-Systems innovation

Living Lab practices are adopted as a tool to implement beneficial change in emergent settings via the integration of social and technological considerations (e.g., Shin, 2019). Pioneer socio-technical-systems researchers observed the key role of workplace learning in adapting both work practices and technology as a tool to best suit operational needs (e.g., Trist, 1981). Puerari et al (2018) viewed the primary goal of living lab participants as value co-creation, and considered the mechanisms involved. Some of their case study participants had a primary interest in learning, some had a primary interest in producing something, with either activity supporting societal system or product / technology system development. McNeese et al (2000) saw living labs as a

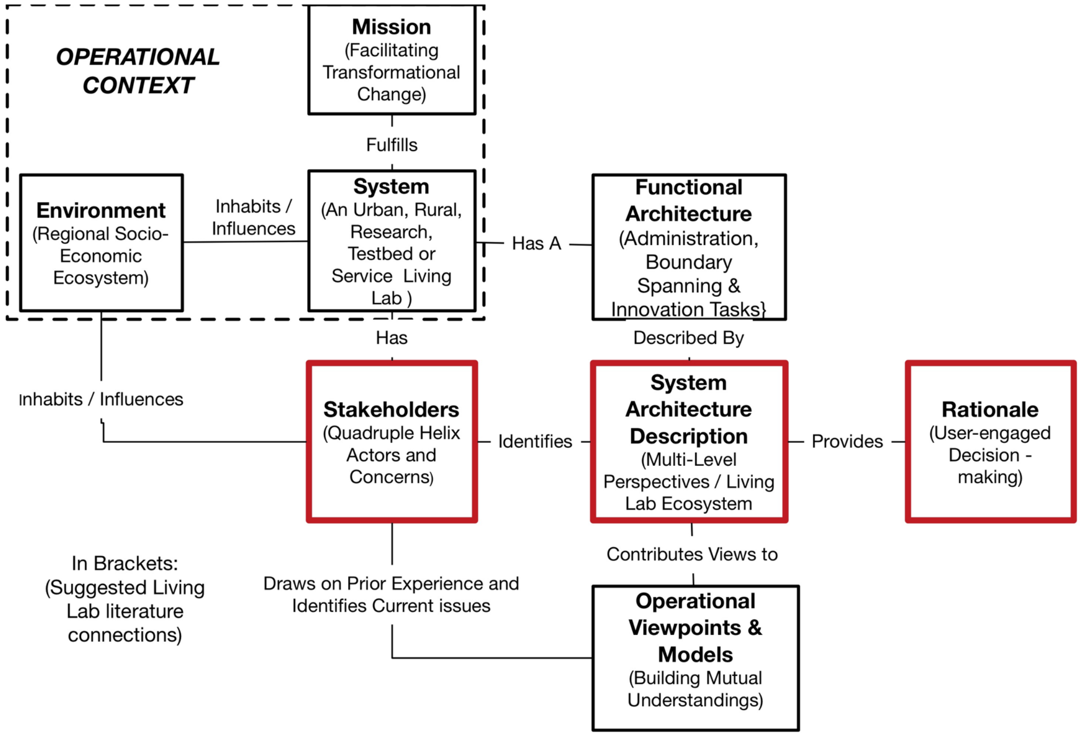

Figure 1. A systems architecture view of Living Lab attributes

mechanism for advancing socio-technical system design. We follow the lead of Rooney (1997) in viewing technology as a tool emerging from the physical (e.g., IT) , biological (e.g., anti-viral drugs) or social sciences (e.g., micro-financing practice). The goal might be to address societal challenges (e.g., Hossain et al, 2019), technology diffusion (e.g. Von Wirth et al, 2019); and/or to support sustainability transitions (e.g., Beaudoin et al, 2022). Budweg et al (2011) viewed living labs as a mechanism for sociotechnical system change to enhance professional community practice. These different perspectives may mean there are different measures of success (e.g., Ståhlbrös, 2013). Kalinauskaite et al (2021) drew attention to the need for transdisciplinary collaboration in living labs addressing societal challenges. Schuurman et al (2016) saw living labs as a place for knowledge exchange, supporting context research and co-creation and as extensions to testbeds. The achievement of these goals requires the use of knowledge and technology resources.

Leminen (2013) had considered living lab innovation engagement practices. Four interaction mechanisms derived from the combination of two coordination practices - top-down and bottom up and two engagement practices - inhalation (drawing users in) and exhalation (reaching out to users) were identified.

Our representation of a living lab socio-technical landscape combining the foregoing ideas in terms of a measure of success, the primary innovation domain, and associated resource attributes is shown in figure 2, followed by insights into each domain.

Social problem driven - Societal application domain

- Measure of success: supporting delivery of community socio-economic benefits.
- Innovation domain: user-driven (bottom-up / stakeholder "inhalation" dominated). Social, organisational, ecological innovation.

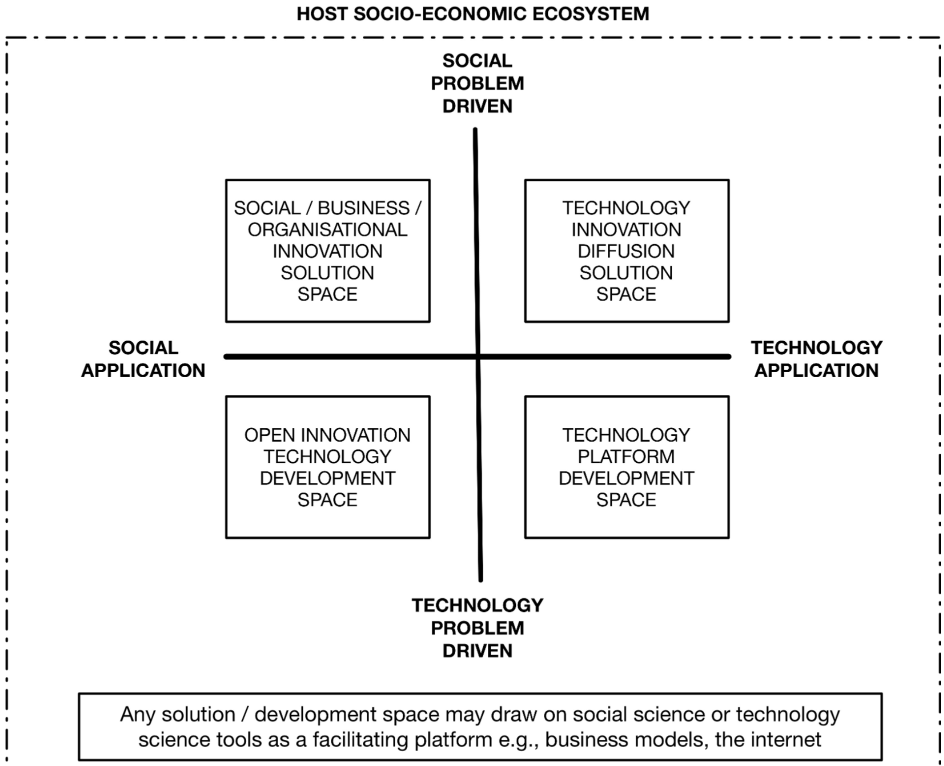

Figure 2. Four generic Living Lab Socio-Technical System innovation domains

- Resources: drawing on an established technology platform(s) (e.g., ICT - Cossetta and Palumbo, 2014; business models - Hossain et al, 2019)

Social problem driven, Technological application

- Measure of success: transformational change arising from technology diffusion.
- Innovation domain: utilizer-driven (top-down / stakeholder "inhalation" dominated). Innovation domain: adaptation, recombinant innovation.
- Resources: drawing on an emergent technology platform(s) (e.g., new renewable energy sources - Canzler et al, 2017)

Technological problem driven – Societal application domain

- Measure of success: Technology development to address a societal challenge.
- Innovation domain: enabler-driven (bottom-up / stakeholder "exhalation" driven), open innovation, inclusive innovation.
- Resources: drawing on an emergent societal knowledge platform(s) (e.g., indigenous knowledge - Gumbo et al, 2012)

Technological problem driven – Technology application domain

- Measure of success: The deployment of technology platforms supporting independent / interdependent technology applications.
- Innovation domain: provider-driven (top-down / stakeholder "exhalation" driven), technological innovation.

- Resources: drawing on knowledge contributions from established communities of practice (e.g., in transdisciplinary projects associated with the world of industry 4.0 - Hervás-Oliver, 2021)

The use of the term socio-technical systems might be questioned in relation to the social problem-societal application quadrant. Firstly, we view technology as a tool developed by people for use by people in the pursuit of a goal, and that such a tool may have its origins in the physical sciences (a machine), the biological sciences (a medication such as insulin) or in the social sciences (e.g., micro-finance systems, business models) (e.g., (e.g. Rooney, 1997). Secondly, these tools may be used as a platform facilitating activities across a wide variety of socio-technical systems.

It is noted that some living labs are established as a platform supporting multiple projects, reflecting the adoption of living lab practice as a strategic tool, and some are established to support one project. So whilst a platform living lab may focus on a particular figure 2 domain, individual projects sponsored may be situated on other domains to support infrastructure development.

2.6 Living Lab Context (4): An operational activity perspective

Soini et al (2023) had noted that the influence of context on co-creation processes is insufficiently recognised, particularly when considering nature-based solutions and discussed the value of a relational place-based approach in living labs. They suggested the co-creation process should be viewed as a 'dynamic confluence of many interconnections.'

Veeckman et al (2013) viewed living lab contextual factors as: real world context of an innovation application and the associated community, matters of lifespan and scale, the level of openness to knowledge sharing and new partners, an ecosystem perspective recognizing the independence and interdependence of associated actors, and access to technical infrastructure. Living labs bring together resources as a tool to facilitate operations. These may include financial, knowledge, infrastructure (e.g., Burbridge et al, 2017), social capital (e.g., Bartelt et al, 2020) and procedural (e.g., Huang and Thomas, 2021) resources.

Living labs have an activity focus supporting specific kinds of learning activities (experimentation and testing) and operational tasks. Guzman et al (2013) viewed living labs as an element of innovation infrastructure that helps maximise the socio-economic conditions of the partners involved. They identified a process reference model having five activity components, each involving multiple stakeholders and having multiple sub-tier activities. We interpret these activities as administration, boundary spanning and project tasks. Zurita (2008) drew on cultural-historical activity theory (Engeström 1999) to study user involvement activities in a rural living labs project. This theory represents learning-by-doing with the aid of tools in a community-engaged context. Some application examples are: integrating inside and outside innovators (Neyer et al, 2009), viewing knowledge work as collaborative work (Iivari and Linger, 1999), collaborative knowledge building (Singh et al, 2009), understanding cultural innovation (Tjahja et al, 2017), assessing NGO impact (Kelly, 2018).

The authors have utilized this theory as a foundation in variety of situations. It was found that the theory made intuitive sense to practitioners if the elemental descriptors were adapted. A representation of the Activity Theory framework and suggested elemental descriptor terminology in a living labs context is shown in figure 3.

Some properties of the Cultural-Historical Activity Theory framework are:

- The same logic can be used to frame multiple levels of analysis, adapting to the specific object and outcomes. Shuurman (2015) indicated that multi-level analysis is needed to understand living lab operations at organisation, project and project task levels. Some

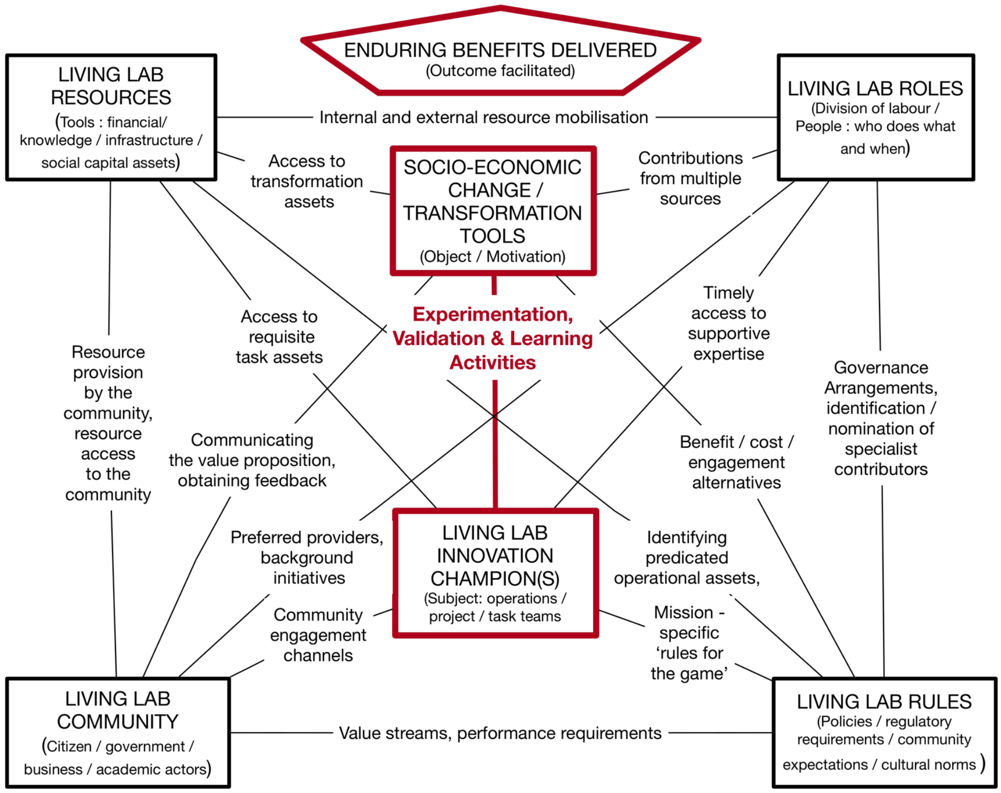

Figure 3. A Cultural-Historical Activity Theory-based Living Lab operational process reference model (Author adaptation)

researchers (e.g., Budweg et al, 2011; Shin, 2019) have suggested an additional, higher level strategic view is needed.

- The framework has recursive properties - the object may, for example, be to undertake the establishment of a team (e.g., Priday and Pedell, 2017), to identify / develop tools (e.g., Mulder et al, 2007) or to agree rules (e.g., Taylor, 2021). Each of these activities will involve identifying what the intended outcome is, who will undertake the activity (subject), how resources (tools) will be used, why the activity is being undertaken (rules), where (community) and when (influencing the division of labour).
- There may be tensions or 'contradictions' within each framework component, between components and between sets of components that provide opportunities for innovation (Engeström 1999). For example Hakkarainen and Hyysalo (2013) describe tensions between actors and tensions between one group of actors and new norms (rules) in a health technology living lab. In previous applications we have utilized a 6×6 component interaction matrix to provide a vehicle for considering such matters, but space does not allow elaboration here.

In practice, using figure 3 as a living lab reference model prompts questions about operational matters. For example, which tools are provided by the community as a resource, and which tools are used by the community in supporting the object? Which rules are imposed by the community and which rules does the community draw on in making its contribution? Which community members need to be engaged in a particular activity?

2.7 Living Lab Context: (5) a focus on outcomes and learning

Living Lab outcomes sought may be: enhanced innovation skills (Herselman et al, 2010), tools to address a societal challenge (Hossain et al, 2019) the facilitation of technology diffusion (VonWirth et al, 2019) or support for sustainability transitions (Beaudoin et al, 2022). New knowledge, validated solutions, professional development, and social capital impact may also be outcomes (Schuurman and Leminen, 2021). Mulvenna et al (2010) had suggested the concept of absorptive capacity enhancement could be useful in considering the interaction between traditional knowledge and new knowledge from external sources in a living lab environment. Ersoy and van Bueren (2020) considered the combined regional impact of urban living lab learning and innovation, noting the impact of learning from experimentation and learning from informal 'reciprocal experiences' extended beyond the individual learning lab.

Given the focus on collaborative learning and knowledge creation / diffusion one important facility is access to a variety of learning spaces. Particular kinds of space may be needed for different purposes and at different stages of a project or learning cycle (Leminen, 2013; Markkuola et al, 2013; Veeckman, 2013; Schuurman et al, 2016). A particular living lab may be viewed as establishing a purposeful learning architecture (e.g., Cousin and Deepwell, 2005) framing what has to be learned *for* engagement and knowledge exchange and what is to be learned *from* engagement and knowledge combination. Our background research has suggested that one learning space supports the identification of learning imperatives - what has to be learned and when. Another learning space helps identify who needs to learn and why to deliver previously identified organisational learning outcomes. Appropriate learning mechanisms and tools are identified in a third space which helps identify where learning may take place and how. The design of spaces providing particular functionality to support different learning cycle stages and their characteristic architecture is suggested as a topic for further research.

Cultural-Historical Activity Theory (see previous section) has also been used as a reference model to support the development of learning systems (e.g. Lee, 2011). The linkage of experiential learning processes and learning spaces (e.g., Kostiainen, 2002) is also suggested as a topic for further research.

2.8 In summary

We had considered living labs as a systematic operation, e.g., as a socio-technical system (Shin, 2019) or a knowledge system (Lehmann et al, 2015). We utilized systems engineering ideas to help map their multiple attributes. We then adapted four theory-based ideas that had previously been used in different settings: (a) representing operational context that frames a living lab mission as a regional socio-economic ecosystem, (b) representing mission enactment context as a system architecture model combining functional and stakeholder perspectives, (c) representing the functional outcome as a form of socio-technical innovation, and (d) suggesting an activity reference model based on Cultural-Historical Activity Theory that can be used to frame multiple levels of community-engaged activity. We also noted the importance of learning and outcome assessment, and proposed those topics as future research opportunities.

In the following we illustrate examples of the socio-technical solution space reference model, then draw on a project from one case to illustrate the use of the Cultural-Historical Activity Theory reference model, This is followed by a cross-case comparison showing attributes of the respective regional socio-economic ecosystems they are embedded in.

3 Linking theory and practice: some illustrative case examples

A case study methodology was adopted, which according to Yin (2014) is appropriate in exploring questions of how and why in a contemporary setting. Case studies may have an exploratory or explanatory orientation. Exploratory studies may be used to collect data to support theory-building. Haverland and Blatter (2012) suggest an appropriate explanatory study methodology is dependent on the research goal. A goal may be to test if a particular variable makes a difference or to compare the explanatory merits of alternative theories or to help understand what makes a particular outcome possible, revealing the interplay between multiple influence factors. The latter approach has been adopted to illustrate the application of the theoretical models introduced in the previous section. Cases were selected from the Australian Living Labs Innovation Network membership list to facilitate local data collection. As noted earlier, case data was assembled in a searchable commercial library system (Eaglefiler) that allowed tabs and notes to be associated with each data item. A purposeful sampling strategy was used to represent the variety of socio-technical innovation domains suggested in figure 2. One case where we had access to a greater depth of data was selected to illustrate the community-engaged activity view shown in figure 3. A cross-case comparison showed linkages with the regional socio-economic system

3.1 Delivering an innovative socio-technical system product

Four illustrative cases are presented, outlined in terms of the structure of Figure 2: measures of success, innovation domain and primary resources.

Case 1. The Ginninderry Living Lab: social innovation through societal engagement.

A living lab has been established with the University of Canberra as a joint venture with a public-private partnership that is developing a completely new suburban precinct on the edge of Canberra. The precinct is intended to 'inspire a new way of living' by setting high sustainability standards with strong community engagement.

Table 1. Gininderry Case description.

Socio-Technical-System Attribute	Case Descriptor
Measure of success: supporting delivery of community socio-economic benefits	The community itself may be viewed as a living lab as there is some emphasis on value co-creation - "When you move to Ginninderry, you become part of the Ginninderry story". Principles for partnering, evaluating, ecological , social and cultural, and economic activities have been established, and progress is regularly evaluated. One example is the SPARK program where vocational learning arrangements are negotiated with employers and multiple education providers. The joint venture has won a number of regional excellence awards for its innovative initiatives.
Innovation domain: user-driven (bottom-up / stakeholder "inhalation" dominated). Social, organisational, ecological innovation.	The Ginninderry Living Lab has been established to guide research priorities and data collection throughout the precinct. The Ginninderry learning lab JV with the University of Canberra is a founding member of the Australian Living Lab Innovation Network (ALLiN) which aims to foster collaboration between practitioners in Australia, Europe and the Asia Pacific. Research Projects for Ginninderry are managed by a Research Steering Committee to ensure oversight and budget allocation. The committee is made up of project staff and a peer reviewer. There are a range of community initiatives being pursued, e.g., in relation to conservation of energy, water and the natural environment. After some discussion, it was decided this research living lab should focus on a community health and wellbeing theme.

Socio-Technical-System Attribute	Case Descriptor
Resources: drawing on an established technology platform(s)	Ginninderry is being established as a 'smart' and 'green' city with widespread adoption of cloud computing infrastructure and low energy households, and these underpin many of the social innovations being pursued. It has been noted this can cause some tensions between traditional actors and their associated 'rules'. IT platforms are used to facilitate transparent knowledge - sharing across the community. For example an on-line library has been established to capture records of all developmental activities and news items related to Ginninderry since its inception.

Case 2. The Western Sydney University Living Labs: social innovation through technological engagement

Western Sydney University (WSU) has 13 campuses across Sydney and supports technology-enabled learning facilities complemented by heritage buildings that have defined its campuses for decades. It was ranked in the top 2% in the Times Higher Education World University Rankings 2022. Its mission links its activities to the development of the Greater Western Sydney region. The multicultural community of the region is quite diverse, hosting over 100 resident nationalities. WSU was one of the original 29 signatories to the Talloires Declaration, a global coalition of more than 400 universities in 78 countries that have made commitments to environmental sustainability. Living labs help deliver on that commitment (e.g., Filho et al, 2023) and WSU supports 20 living lab initiatives associated with particular UN Sustainable Development Goalss.

Table 2. WSU Case Description.

Socio-Technical-System Attribute	Case Descriptor
Measure of success: supporting transformational change from technology diffusion	The essential components of WSU Living Lab initiatives are seen as providing a multidisciplinary focus and identifying some broader strategic opportunities. Initiatives developed to date include living lab responses to broad societal issues of urban development, natural and cultural heritage, renewable energy, urban heat, water recycling, and peri-urban food systems. Success is measured firstly in terms of individual lab contributions to the achievement of targeted UN SDGs and secondly by the flow of students into the community as environmentally responsible citizens, consistent with the Talloires Declaration.
Innovation domain: utilizer-driven (top-down / stakeholder 'inhalation')	The aim is to engage students and the broader community in experimenting with and testing a variety of ideas. For example, the Hawkesbury campus reflects a best practice demonstration of peri-urban landscape management. The campus footprint of 1,400 hectares includes a built campus of 300 hectares, commercial farm and environmental assets of 600 hectares and 400 hectares of remnant Cumberland Plain vegetation. Both the Hawkesbury Water Recycling Scheme and the Hawkesbury Farm are long established Living Labs for teaching, research and demonstration. Water recycling connects risk management needs in the fragmented peri-urban landscape, with benefits reflected through the water cycle. There is some interaction between WSU living labs that have overlapping interests, e.g., in applying IoT technologies in agriculture.

Socio-Technical-System Attribute	Case Descriptor
Resources: drawing on emergent technologies	Resources include a variety of continuously evolving physical spaces where emergent technologies can be trialled and access to those technologies is provided. Some other campuses where a university is seen as a living lab have experienced tension between academic users of assets and those responsible for their establishment and maintenance. Through more than 20 years of experience, WSU has developed a strategy of incorporating experimentation features in its assets, e.g., including extra sensors and data collection facilities in its 'smart' buildings.

Case 3. The Swinburne Living Lab: technology innovation through societal engagement

The Swinburne University of Technology Living Lab is a program within the Centre for Design focused on solutions promoting greater health and wellbeing across the lifespan and in ageing populations, particularly those living with dementia. It is accredited with the European Network of Living Labs organisation and is a founding member of the Australian Living Lab Innovation Network. The lab has five supporting partners. These are a national industry peak body, Dementia, Australia, a local government authority, a regional healthcare network, a small local IT consultancy and a small local education technology firm. The Swinburne Living Lab provides a multi-project platform and has a core team of eight researchers.

Table 3. The Swinburne Case Description.

Socio-Technical-System Attribute	Case Descriptor
Measure of success: technology development to address a societal challenge.	Two measures of success have been adopted. Firstly technology development /adaptation to address a societal problem - living with dementia as a population ages, primarily contributing to a toolkit to be utilised with Dementia Australia, and secondly, supporting the delivery of community socio-economic benefits through a net reduction in healthcare costs as may be verified in conjunction with its healthcare network partner.
Innovation domain enabler-driven (bottom-up, stakeholder 'exhalation' driven).	Some projects are situated in the technology innovation / social space (e.g., exploring the use of virtual reality tools to help people with dementia) and some in the social innovation / social space (e.g., delivering co-design training for practitioners and researchers using a sector-specific toolkit). Some specific project examples are: - identifying stakeholders and knowledge flows in dealing with dementia patient management (Keirnan and Pedell, 2020); - a local community 'active ageing' portal to provide one place where citizens can find support services and targeted programs (Priday and Pedell, 2020); - the development of a serious board game simulating the multiple interactions involved in dealing with community member homelessness issues (Belinda et al, 2022); - building older adults' confidence in technology use through co-designing digital storytelling (An et al, 2023).

Socio-Technical-System Attribute	Case Descriptor
Resources: drawing on an emergent knowledge platform.	Resources include access to a variety of university centres of specialisation and the networks of external partners. One issue with this living lab is identifying conditions and processes for extracting knowledge from the community of users it is engaged with. As noted by Kanstrup (2017) there can be carer time and priority conflicts to be worked through and issues of user absorptive capacity to be identified. This brings a focus on community-specific engagement and knowledge capture mechanisms and the time it may take to implement appropriate approaches.

Case 4. The Westmead Living Lab: technology innovation through community of practice engagement.

The Westmead Living Lab has been established and operated by the University of Sydney in a large health-oriented innovation precinct and is founded on four strategic pillars:

- collaborative decision-making with its community and partners
- inter-disciplinary problem solving and knowledge transition
- data commons - mobilising data capacity, and,
- precinct focused projects

Table 4. The Westmead Case Description.

Socio-Technical-System Attribute	Case Descriptor
Measures of success: the development and deployment of technology platforms.	Success is measured via the impact the living lab has on its partners; providing high quality and sustainable healthcare in the region and beyond, creating and attracting new industries and developing global talent. One objective is to host 6000 students by 2030. Operations support the co-creation of "implementable and scalable solutions to real world problems via multiple focused research and education projects targeting diagnostic sciences and technologies, person-centred care and sustainable health".
Innovation Domain: researcher driven (stakeholder top-down / 'exhalation' driven) transdisciplinary innovation	The innovation focus is on the establishment of innovative health diagnostic and intervention technology platforms, bringing together health practitioners, education and multiple research partners in their development and commercial deployment. Engaging with external communities of practice in the multi-billion dollar regional innovation precinct helps both identify unmet needs and demonstrate the utility of the technology platforms. This is one of four State Government supported innovation precincts, each with a different focus, but all aiming to stimulate economic activity.
Resources: drawing on knowledge contributions from established communities of practice.	A purpose-built facility has been established in a health innovation precinct where there are four hospitals, two university research centres and one government research centre that can be involved in projects. Spaces have been provided to host global health industry business partners and a business incubator is associated with the living lab to support IP deployment by entrepreneurial start-ups. It is estimated the precinct will ultimately attract 20,000 professionals who will draw on and contribute to living lab projects. An associated research centre has been established to mobilise data capacity which enables digital transformations in health practice.

3.2 Characterizing a community-engaged project activity system (case 5)

A Swinburne Living Lab (case 3) community engagement project was chosen to broadly illustrate an application of the Cultural-Historical Activity Theory model (figure 3). This case also illustrates the recursive nature of the Activity Theory model as the aim is to identify the community to be engaged and the likely division of labor in associated living lab projects.

Table 5. A project-specific Activity Theory representation of interacting components.

Living Lab Activity Theory Component (figure 3)	Swinburne Living Lab example (Keirnan and Pedell, 2020)
Outcome: enduring benefits delivered meeting a community need, enhanced regional socio-economic capacity.	Project outcome sought: building teams, identifying co-design stakeholders and engagement mechanisms in healthcare projects with complex stakeholder considerations. (e.g., Kanstrup, 2017; Huang et al, 2022). Outcomes realized: the identification of an expanded group of actors to be engaged with a number of potential barriers between them.
Object: socio-technical system development and deployment activities, knowledge sharing, experimentation and testing activities providing tools to support change / transformation.	Knowledge extraction and representation via a series of activities: a literature review, initial interview with healthcare organization staff, three co-design workshops with organization staff and clients surface values, potential issues and service expectations
Subject: living lab innovation champion(s) strategic, operational or project value co-creation team	A university team working with health workers, service users and medical practitioners to identify all community of user and community of practice participants
Tools: financial, knowledge, technological infrastructure resources utilized in undertaking the activity and enhanced by undertaking the activity	Tools used were literature reviews, interviews, workshops facilitating iterative co-design activities, clarifying the nature of problems and solutions, knowledge flow mapping tools and visualizations of the results they produced for use as boundary objects.
Rules: policy, regulatory, business rules, community expectations and cultural norms	Rules were associated with healthcare management and government support, client and service provider expectations. Some tensions associated with working rules were: (a) some types of treatment required could not be bulk-billed to Medicare (b) patient data could not be widely shared, (c) patients not registered with National Health could be hard to reach, (d) GPs are time poor and cannot always engage with other actors.
Community: users and professional communities of practice, quadruple helix actors	In addition to the researcher community, the study engaged with client/carer service users, medical/service access providers and clinical services communities. It was noted that initially there was no direct interaction between the clinical services and client communities, with no spaces for triadic interactions.
Division of Labor: roles and responsibilities, governance arrangements, innovation management and boundary spanning roles at different life-cycle stages	An iterative process of surfacing issues and connections identified six kinds of actors that played a team role at different times. They were: the researcher, the healthcare CEO, a community services portfolio manager, an allied healthcare specialist, a local government neighborhood house service manager and a local government community care manager.

One point to be made here is that the structure can be used to both plan projects and reflect on their outcomes, e.g., who was involved and what did they learn?

3.3 Regional socio-economic ecosystem pathways

What is seen as constituting a region varied between the cases 1 to 4 outlined previously. The Ginninderry case was associated with a new community precinct where a living lab provided research services. The Western Sydney University living labs supported technology diffusion over a much larger area covering urban and peri-urban settings with a population of about 1.8 million. The Swinburne case served a localised industry sector learning which digital technologies might support that sector and how. The Westmead living lab served a large-scale health technology innovation precinct, mediating between basic research and professional communities of practice. The budgets of the case examples ranged from very small in the Ginniderry case to very large in the Westmead case. There were differences in the cases in the way they engaged with innovation, business and knowledge ecosystems, as outlined in table 6.

4 Discussion and Concluding Remarks

The intent of this paper is to introduce theoretical foundations from other fields that can support the design of a living lab viewed as a system of systems. Explanatory case studies are used to illustrate the application of theoretical concepts introduced. Prior research (e.g., Schuurman, 2015) had indicated multi-level analysis was needed to understand the dynamics of living lab operations, considering the living lab, projects undertaken and the nature of interactions within project activities. We have added a fourth meta-level of analysis - engagement with the regional socio-economic ecosystem the living lab draws on and contributes to (e.g., Scholl et al, 2022). We suggest that living labs with comparable objectives situated in different time-place settings may follow different pathways.

The material presented in section 2 (related work and theoretical perspectives) suggests living labs make three contributions to outputs. These are: (a) enhanced participant absorptive capacity and knowledge created from experiential learning, (b) socio-technical artifacts that provide a platform for further development, and (c) some form of co-created value (economic, environmental, social) that gives something back to the participants investing their time and resources in the living lab. This allows participants to realize value-in-use of the knowledge /artifacts produced, and broader community value-in-impact from the outcomes. Guzman et al (2013) had represented the latter in terms of what an actor could contribute that was valued by others and what the actor valued in terms of accessible assets. As the authors have observed in other multi-partner collaboration settings, there may be some time before the full benefits are realized, and how a benefit could be appropriated to the living lab as compared with external action taken by participants can be problematic. For example, in case 1, the physical artefact is a report which may or may not be successfully acted on. In case 2, one outcome is support for a community sustainability culture progressively delivered via a flow of graduates. In case 4 the outcomes may be an economic benefit from intellectual property use and a flow of informed graduates. It is suggested that one way of addressing this aspect is to focus on the living lab role of co-creating knowledge through purposeful learning, framing what had to be learned and when, by who and why, and where and how, and considering if this happened. This is suggested as a topic for future research.

The literature raises questions about business models that support the ongoing viability of living lab practice. Whilst the establishment of living labs may attract direct government support in some parts of the world, this is has not been the position in the Australian cases presented here. Instead, they have had to make sense in some overarching context that may include government support,

Table 6. Socio-economic ecosystem linkages.

Illustrative case and socio-economic context	Socio-economic system engagement pathway		
	Innovation ecosystem linkage	Business ecosystem linkage	Knowledge ecosystem linkage
Case 1. Ginninderrry: strong state government engagement supporting social innovation in an emerging socio economic zone.	Social innovation driven by a community vision, some projects directly associated with the living lab, some implemented separately.	Supporting and supported by a public-private partnership and two regional universities declaring some local 'rules' and providing various resources.	Stimulating community learning via a virtual enterprise engaging multiple vocational and university providers.
Case 2. Western Sydney University: a focus on UN SDGs and meeting an international agreement commitment.	An applied sustainability research orientation with some project-specific linkages between different living labs and university research centres.	Funding and physical assets provided by the university that viewed its campuses as living labs. Strong community engagement and social capital.	Stimulating university student experiential learning, supporting the inclusion of a sustainability theme through multiple courses to maintain a supportive culture.
Case 3. Swinburne: local government and industry engagement in a strong economic region	Applied research link with university research centres and, SME partners as independent healthcare system researchers and research users.	Some funding and physical facilities provided by the university. Aged care sector and local government partners providing some access to resources.	Stimulating community sector learning, providing learning tools.
Case 4. Westmead: strong state government engagement in a strong economic region	Diffusion of emergent basic medical research via multiple mechanisms, particularly via lead users.	Health care and health technology industry actors, academic actors and government actors stimulating regional economic activity.	Stimulating transdisciplinary professional community of practice learning, supporting a flow of new specialists.

e.g., case 4 (Westmead) in the context of establishing innovation precincts. This highlights the need for fit with the regional socio-economic ecosystem.

4.1 Contribution to theory

The academic literature views living labs from multiple perspectives, e.g. in terms of functionality, stakeholder engagement and challenges. With this in mind, we have presented an adaptation of an established systems engineering architecture description standard (ISO 42010:2022) to illustrate how these attributes are connected in establishing living lab operational context (see figure 1).

The first of our research questions was *'how may different modes of user engagement be associated with particular kinds of innovation activity'*? The response presented here is: *by association with a particular generic socio-technical problem solution domain*. Four potential solution domains are characterised in terms of measures of success, collaborative innovation characteristics and resources utilised. Each domain represents a particular instance of social or technology problem drivers combined with a social or technology application space (see figure 2). Australian living lab case studies are presented to illustrate operations within each domain in practice.

Our second research question was ' *how may proposed reference models be used to characterise living lab context and operations'*? The response presented here, which draws on reference models we have previously used in other collaborative enterprise settings is: *by providing multi-level perspectives in establishing context and characterising interaction activities*. Context is established viewing living lab operations as systems of systems within a broader ecosystem (figure 1). This model was selected based on the authors practical experience using it to help describe as-is and to-be complex private-public partnerships undergoing transformational change. Living lab operations involve multiple interactions between different kinds of actor, and a model based on Cultural-Historical Activity Theory is presented. The core logic of this theory is that (a) a subject draws on tools to undertake activities (experimentation and validation in the living lab case) targeting a specific object, and (b) that the subject, object and tools are linked to matters of context represented in terms of rules, the associated community and a division of labour. Our experience using this model with business and government practitioners has been that if the terminology is changed, it makes perfect sense to them. Following this lead we have adapted the theory terminology consistent with observations from the living lab literature, e.g., the 'subject' is an 'innovation champion' and the 'division of labour' is 'roles and responsibilities' (see figure 3). This generic model supports analysis at multiple levels of detail and helps understand interactions between multiple influence factors. An illustrative example of a project within one of our living lab cases is provided.

4.2 Contribution to practice

Living labs are seen as a form of regional collaborative innovation intermediary that facilitates active user / community engagement with academic, government and business actors to deliver valued solutions to societal issues. Two kinds of outcomes are observed. Firstly, evolution of a socio-technical system where the technology involved may be founded in the physical, biological or social sciences. Secondly, leverage from stakeholder mutual learning , knowledge creation and diffusion, and social capital enhancement that may spill over into subsequent initiatives.

The way these outcomes are progressed and delivered is seen to be dependent on the motivation and resources within the socio-economic ecosystem the living lab is situated in. A subsidiary innovation ecosystem is seen as supporting value creation. A subsidiary business (including government enterprises) ecosystem is seen as supporting value capture and delivery. A subsidiary knowledge ecosystem is seen as supporting the development of value-in-use. Case studies provide an illustration of these linkages in four Australian regional settings (see table 6).

With regard to questions regarding living lab impact, a paucity of academic studies focused on outcomes is noted in the academic literature. There is a stronger focus on inputs and process (e.g., Paskaleva and Cooper, 2021). This may be because living labs facilitate the work of others in delivering outcomes, and it may be some time before the full impact is felt. We have taken the view that investors and participants in living labs will be attracted to the value proposition represented in the living lab goal. A living lab may help enhance social and/or economic capital for the context it is embedded in, and whilst some up-front effort is needed, this pays off in the long run. What is valued may take different forms, and participating actors may realize value-in-use in different ways (e.g., through connections made or benefits of technology use).

4.3 Limitations and suggestions for further research

The paper has a number of strengths and limitations. Whilst bringing together multiple viewpoints and their associated models is seen a strength in defining complex systems (e.g. ISO 42010:2022), showing how the associated viewpoints work together in a living lab context requires further research. Interaction between multiple elements is a living lab recurring theme that is represented in the models presented, but space has not permitted detailed description of this aspect. A further limitation is the ability to fully represent all concepts in detail in one paper. In particular, the dynamic interaction of experiential learning processes and the provision of learning spaces requires further elaboration (see e.g., Kostiainen, 2002). The use of pattern language practice to capture and share knowledge from disparate sources is suggested as another research topic (see e.g., Akasaka et al, 2020). Outcome and impact assessment methodology is seen as a topic for further research (see e.g., Dekker et al, 2021)

Most of the living lab literature describes academia-driven initiatives. Considering living labs as business and community initiatives may be a topic for further research utilising tools presented in this paper. In addition, whilst living labs may be seen as places supporting innovation, we suggest that some places may be viewed as living labs hosting an independently evolving innovation milieu, e.g., in case 1 (Ginninderry) an urban setting, and case 2 (WSU) a university campus(s).

Acknowledgement

The authors received no financial support for the research, authorship or publication of this article.

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