School of Design and the Built Environment

Curtin University Sustainability Policy Institute

Low carbon transition through innovation at the university-industry-government nexus

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This thesis is presented for the Degree of Doctor of Philosophy of

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Human ethics

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number RDHU-49-16.

Signature of candidate:

Date: 11 January 2022

Statement of contributors

I, Mike Burbridge have conceived and coordinated all the written materials submitted as part of this PhD by publication (hybrid). I also undertook the majority of the writing and analysis for each publication.

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Co-authors' statements

Publication 1

I, Mike Burbridge, contributed 90% to the publication entitled:

Burbridge, M. & G. Morrison (2021)

A systematic literature review of partnership development at the university-industry-government nexus.

Signature of candidate

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Date: 11 January 2022

I, as a co-author, endorse that this level of contribution by the candidate indicated above is appropriate.

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Business models for sustainability in living labs. In Living Labs: Design and Assessment of Sustainable Living, pp 391-403.

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Proceedings of the 7th International Conference on Energy and Environment of Residential Buildings, edited by Miller, W., Susilawati, C. and Manley, K. Brisbane: Queensland University of Technology, Australia.

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Abstract

The industrialised world is continuing along a path of economic transformation. Economic growth is increasingly reliant on the development and exploitation of knowledge. This places those who create knowledge and those who commercialise it in a prominent role, as well as being the focus of government attention. Evidence from best practice has led to the current discourse that suggests that partnerships at the university-industry-government nexus are required to effectively commercialise knowledge and enable innovation.

This research demonstrates that in the literature there are two typologies of partnership for innovation at the university-industry-government nexus. One is referred to as top-down and involves the creation of largely new structures by management to promote the commercialisation of knowledge. The second form of structure is less well defined but is referred to as bottom-up. Bottom-up structures are initiated from within the partnership and are characterised as being user centred with the adoption of open innovation. One example of the bottom-up artefact is the living lab.

This research finds, through the adoption of a systematic approach to the analysis of latent data, that top-down partnership structures are primarily focused on the economic benefits of innovation. The research demonstrates that a reason for this focus is that top-down structures have their origins from a time when knowledge production was more discipline based (Mode 1) and before the widespread democratisation of knowledge or globalisation of the environment. The research suggests that the phenomenon of top-down partnerships remaining primarily focused on economic growth can be partly explained through path dependence theory.

This research also demonstrates that it is only bottom-up structures that provide the innovation to enable a low carbon and sustainable transition. The research suggests that one reason for this is that bottom-up structures were created in a period when knowledge production was more transdisciplinary (Mode 2) and at a time when the globalisation of society was giving global citizenry a greater voice (resulting in Mode 3 knowledge production) with the globalisation of the environment concomitantly receiving greater policy attention.

The research also demonstrates that there is nothing preventing top-down partnerships from pursuing low carbon or sustainable innovation, which suggests the reasons for lack of sustainable innovation are institutional rather than structural.

This research proposes a theoretical metastructure to enable innovation at the university-industry-government nexus. The metastructure integrates the evolution of partnerships with the globalisation of the economy, society and environment and the changes in modes of knowledge production. This results in three streams of partnership development. Stream 1 involves the development of on-campus structures; stream 2 is the development of campus adjacent structures and stream 3 is the creation of living labs (and derivatives).

The three streams help to explain why top-down structures have a primary economic focus. To address this issue the research proposes an institutional framework to enable Stream 1 and Stream 2 partnership structures to evolve through the application of knowledge, to partnership structures that embrace co-creation and open innovation to enable a low carbon and sustainable transition through innovation at the university-industry-government nexus.

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They say it takes a village to raise a child; well, the same is true for completing a PhD. I have been fortunate to be showered with love and support during the creative process that has led to the submission of this work.

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List of publications

The following are the publications resulting from the research for this thesis.

Publication 1: **Burbridge** & Morrison (2021)

Burbridge, M. & G. Morrison (2021)

A systematic literature review of partnership development at the university-industry-government nexus.

Sustainability 13, no. 24: 13780. https://doi.org/10.3390/su132413780

Publication 2: Burbridge, Morrison, van Rijn, Silvester, Keyson, Virdee, & Baedeker (2016)

Burbridge, M., G Morrison, M. van Rijn, S. Silvester, D. Keyson, L. Virdee, & C. Baedeker (2016).

Business models for sustainability in living labs. In: Keyson D., Guerra-Santin O., Lockton D. (eds) Living Labs. Springer, Cham. https://doi.org/10.1007/978-3-319-33527-8_30

Publication 3: Burbridge (2017)

Burbridge, M. (2017)

If living labs are the answer – what's the question?

Procedia Engineering, Vol 180 pp 1725 – 1732

Publication 4: Burbridge (2018)

Burbridge, M. (2018)

A Study of Australian Universities' Collective Response to Climate Science.

In: Sayigh A. (eds) Transition Towards 100% Renewable Energy. Innovative Renewable Energy. Springer, Cham. https://doi.org/10.1007/978-3-319-69844-1

Publication 5: Burbridge & Morrison (2016)

Burbridge, M. & G Morrison (2016)

Happy Homes – the Relationship between Homes and mental wellbeing.

Proceedings of the 7th International Conference on Energy and Environment of Residential Buildings, edited by Miller, W., Susilawati, C. and Manley, K. Brisbane: Queensland University of Technology, Australia.

Other published work

Publication: Burbridge, M. (2017)

Australian Universities are not walking the talk on going low carbon.

https://theconversation.com/australias-universities-are-not-walking-the-talk-on-going-low-carbon-72411

Publication: Wardell-Johnson, G., Wardell-Johnson, A., Bradby, K., Robinson, T., Bateman, P.W., Williams, K., Keesing, A., Braun, K., Beckerling, J. and Burbridge, M. (2016)

Application of a Gondwanan perspective to restore ecological integrity in the south-western Australian global biodiversity hotspot.

Restoration Ecology, 24: 805-815. https://doi.org/10.1111/rec.12372

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List of abbreviations

CSIRO	Commonwealth Scientific and Industrial Research Organisation
EC	European Commission
EOI	Expression of interest
EU	European Union
FSP	Future Science Platform
GDP	Gross domestic product
IP	Intellectual property
ISA	Innovation and Science Australia
KPI	Key performance indicator
LL	Living Lab
MOOC	Massive open online course
NISA	National Innovation and Science Agenda
OECD	Organisation for Economic Cooperation and Development
PCG	Project Control Group (responsible for delivery of Stage 1 Greater Curtin)
RFDP	Request for detailed proposal
RI	Responsible Innovation (Australian vernacular for RRI)
RIFSP	Responsible Innovation Future Science Platform
RRI	Responsible Research and Innovation (RI in Australia)
SDG	Sustainable development goals
SLR	Systematic literature review
STP	Science and Technology Park
SusLab	Sustainability Living Lab
UIG	University-industry-government
ULL	Urban Living Lab
UN	United Nations

Chapter 1 Introduction

This thesis will investigate low carbon transition through innovation enabled by partnerships for innovation. The research is based on a mixed methods approach and leads, as reported in Chapter 7, to the development of a new metastructure to enable innovation at the university-industry-government nexus.

This introductory Chapter provides the background information that gives rise to the research questions. These questions will be addressed in this thesis through five peer reviewed publications (see Appendix B.1 to B.5), which have been collated and integrated via this exegesis. Further unpublished work is presented in Chapter 5 and an extended literature review (unpublished and presented as Appendix A) also contributed to the findings evidenced in this exegesis.

1.1 Context

In 1959, Peter Drucker [1] wrote about the emergence of a new form of economy – one that is based on knowledge. He did not argue that industrial economies were knowledge free rather that in the emerging knowledge economy, knowledge would become the primary resource for economic growth. He argued that knowledge, in and of itself, only has economic (rather than societal) value when it is used in a task. He predicted many tensions that would arise out of the transformation of knowledge into goods and services. Key amongst these tensions is:

- organisations' desire for autonomy versus society's need to pursue the common good;
- society's desire for stability versus organisations' need to innovate change;
- the strength of specialist knowledge and the needs of the team versus the rising demand for socially responsible organisations.

All of this he predicted would be the challenges for years to come.

1.2 Background

The world's economy has become knowledge intensive, and with the advent of the internet, knowledge is becoming increasingly accessible to a range of stakeholders [2, 3]. In many industrialised economies this has seen the rise in importance of the service

sector for economic output with a reduced emphasis on manufacturing for increasing gross domestic product. In parallel there has been a movement of mass production to less developed economies with a supply of abundant and relatively cheap labour [4].

In such a post-industrial economy, which is increasingly focussed on the commercial exploitation of knowledge, the role of universities in creating and commercialising new knowledge is garnering increased interest in national [5] and international policy circles [6] as well as in academia itself [7]. The process of effectively commercialising new knowledge is seen to be the key to future economic development [8]. It is increasingly being recognised that this economic development needs to be achieved in a manner that is consistent with both the delivery of the United Nations' Sustainable Development Goals [9] and the Paris Climate Accord [10].

There is much in the academic literature concerning the transition to a knowledge economy (see Appendix A for an extended review of the literature and Chapter 2 provides a synthesis of the literature). However, what is missing from the research to date is a model that is designed to enable low carbon and sustainable transition through innovation to help society pursue the common good, deliver the Sustainable Development Goals and enable a low carbon future. A proposed metastructure to help achieve these goals is presented in Chapter 7.

1.3 Research positioning

Before proceeding to the research evidenced in this thesis it is necessary to understand the processes that have led society to the current position.

Since the 1940s there has been a movement by governments to increase the uptake of university research by industry. Initially the focus was on defence and agriculture [7] but over time the purview widened and started to encompass not only policy processes (through funding and incentives, for example the passing in North America in 1980 of the Bayh-Dole Act [11]) but also the creation of structures to help commercialise innovation. This process has been ongoing for over 70 years [12]. In the last decade the globalisation of access to the internet meant that access to knowledge is more freely available [2]. This has led to the acceleration of the development of new forms of intermediaries for innovation and new forms of partnership [13].

There is a considerable body of literature that addresses the need to create partnerships between universities, industry and government with the intention to promote innovation for the further economic development of society [12]. There is extensive research looking at how partnerships – or intermediaries for innovation – have developed [12, 14] and how they are producing outputs that contribute towards economic growth. However, there is a much smaller strand of work – although it is growing (see Publication 1 and [12]) – that considers partnerships to enable innovation that is economically viable, socially just and environmentally sustainable. These intermediaries for innovation are a looser agglomeration of a range of partners. In their current form they do not follow set rules but evolve rapidly and currently they are only localised, although some urban areas have developed networks (Publication 1).

To develop innovation that is economically viable, socially just and environmentally sustainable a new metastructure is proposed in Chapter 7.

1.4 Research questions and objectives

The research positioning leads to the overarching research question of this thesis:

How can universities, industry and government together drive low carbon innovation and transition?

Four sub-questions have been developed to support and elaborate on the primary research question to provide a framework for the research. These sub-questions are:

- Sub-question 1: Which partnership models at the university-industry-government (UIG) nexus have been successful in delivering innovation?
- Sub-question 2: Which partnership models at the UIG nexus have been successful in delivering low carbon and/or sustainable innovation?
- Sub-question 3: What factors promote or limit partnership development for a low carbon future?
- Sub-question 4: How can Australian universities become more effective at partnering with government and industry to drive a low carbon future?

To address these questions, five definitive bodies of work have been published with the full text provided in Appendix B.1 to B.5. The objectives derived from the questions,

and the resulting publications are shown in Table 1.1. A summary of these publications makes up the main body of this thesis. In addition to these publications, Chapter 5 provides results from an unpublished case study of the development of student accommodation at Curtin University which contributes to the findings evidenced in his thesis.

Table 1.1 Summary of the research sub-questions, their objectives and associated publications

Sub-questions	Objectives	Associated publications
Which partnership models at the UIG nexus have been successful in delivering innovation?	To identify the development of partnership models to create best practice partnerships To identify partnership structures that are being used to deliver a low carbon future.	Publication 1: A systematic literature review of partnership development at the university-industry-government nexus Published, peer reviewed article
Which partnership models at the UIG nexus have been successful to deliver low carbon and/or sustainable innovation?	To identify best practice in business case development in partnerships a the UIG nexus	Publication 2: Business models for sustainability in living labs Published, peer reviewed book chapter
What factors promote or limit partnership development for a low carbon future?	To identify those issues that prevent effective partnership creation	Publication 3: If living labs are the answer what is the problem? Published, peer reviewed article
How can Australian universities become more effective at partnering with government and industry to drive a low carbon future	To identify Australian universities' performance in partnering with industry and government; To identify the opportunities for universities to partner with industry, or government; and To identify universities' performance in adopting low carbon research outputs	Publication 4: A study of Australian universities' collective response to climate science Published, peer reviewed article Publication 5: Happy homes – the relationship between homes and mental wellbeing. Published, peer reviewed article

1.5 Thesis organisation

The research undertaken in this thesis is presented in the format of a thesis by publication, with five published papers, and unpublished data integrated *via* this exegesis. A synthesis of the literature review is presented in Chapter 2; Chapter 3 presents the overall research methodology. The research summary for each publication is presented in Chapter 4 alongside a discussion of the progression of the research through the thesis. Chapter 5 presents a case study on a student accommodation project at Curtin University and develops an institutional framework to enable low carbon and sustainable innovation. Chapter 6 provides a synthesis of the research contribution to the literature. Chapter 7 presents a new metastructure to enable innovation at the university-industry-government nexus. Chapter 8 offers recommendations for further research. Appendix A presents an extended literature review and the publications themselves are presented in Appendices B.1 to B.5.

Chapter 2 Synthesis of literature review

This Chapter provides a synthesis of the literature reviewed for this thesis. An extended literature review is presented in full in Appendix A and Appendix B.1 – Publication 1.

This synthesis is formed around the sub-questions that are central to the theoretical findings presented in Chapter 4 and Chapter 6. Section 2.1 provides a summary of the underlying theory that has led to this research. Section 2.2 discusses the theory of partnership development at the university-industry-government nexus; Section 2.3 focusses on the creation of hybrid organisations at the university-industry-government nexus and Section 2.4 concerns the creation of partnerships at the nexus to deliver low carbon and/or sustainable innovation. Finally, Section 2.5 considers issues related to the development of the partnerships themselves.

As a compilation of the literature this Chapter provides a synthesis of the context for the development of the theoretical research findings presented in Chapter 4 - 7. A summary of the literature reviewed is provided in Table 2.1.

2.1 Background

Knowledge is a key factor in driving economic development and growth [1] and the exploitation of knowledge has led to five broad technological transformations that have driven economic growth and prosperity since the industrial revolution [15].

The increased importance of knowledge for economic success has led to increased interest into how to commercialise knowledge to deliver the next wave of economic growth [7]. In turn this has led to increased academic and policy interest into how universities (as knowledge creators) and industry (as knowledge users) and government (as guardians of the public purse and public policy) can effectively work in partnership to develop the next wave of economic growth. For universities, this increased policy attention and opportunity has led to the development of increasingly entrepreneurial institutions where entrepreneurialism penetrates each of their three missions [8]:

- Mission 1: teach;
- Mission 2: research; and
- Mission 3: engage (with society)

Table 2.1 Synthesis of literature reviewed

Section	Literature reviewed	Research question	Thesis narrative
2.2	Partnerships for innovation – models of partnership at the UIG nexus	Which partnership models at the UIG nexus have been successful to deliver innovation?	• Increasingly commercial exploitation of knowledge depends upon a partnership between two or more entities • The focus is the delivery of commercial success and economic growth
2.3	Partnerships for innovation – the creation of hybrid organisations	Which factors promote or limit partnership development for a low carbon future?	• Partnership structures are evolving from a top-down/ bottom-up approach • Top-down approaches are an organisational response to the exploitation of knowledge • Bottom-up structures are more likely to address economic, social and environmental issues
2.4	Partnerships for innovation delivering economic, social and environmental outputs	Which partnership models at the UIG nexus have been successful to deliver low carbon and/or sustainable innovation?	• Partnerships that give voice to public interest are more likely to drive local low carbon outcomes • However, there is little evidence of these partnerships delivering across the sustainable development goals
2.5	Developing expertise in creating partnerships for innovation	How can Australian universities become more effective at partnering with Government and industry to drive a low carbon future?	• Australian universities are weak at collaborating for innovation when compared to their OECD counterparts • Universities need to partner to develop knowledge and experience

The deepening of the knowledge economy has also happened at a time when knowledge is becoming increasingly available for use by a wide range of stakeholders [2, 16]. This development, discussed in depth in Appendix A, has also created academic, policy and industry interest leading to the development of theories around open innovation [17] and user centred innovation [18]. The increasingly ubiquitous access to knowledge has also led to changes in the modes of knowledge production (see Table 2.2 developed from [19-21]) where knowledge production has moved from being discipline based to transdisciplinary, theoretical to increasingly applied and from being organisation based to becoming increasingly distributed (initially to partners but ultimately to society).

Table 2.2 Changes in the modes of knowledge production

Knowledge production	**Explanation**
Mode 1	Discipline based; fundamental
Mode 2	Transdisciplinary; applied and distributed between partners
Mode 3	Transdisciplinary; applied; distributed and democratic

A full discussion of the theoretical approach to innovation in the academic literature can be found in Appendix A.

2.2 Theory of partnership development at the university-industry-government nexus

The development of innovation as a key driver of economic prosperity and improving standards of living led to the concept of national innovation systems [20, 22]. The national innovation systems approach focused on the innovation ecosystems in different countries to understand why some countries were more innovative than others [23]. There are several lessons from the national innovation systems approach but key amongst them relates to tangibility and reproducibility of resources. Tangible resources (for example consumption of energy and materials) are reduced in the economic process whereas non-tangible resources (for example knowledge) can be increased through the process [24].

A weakness of the national innovation systems approach is that it considered innovation as a linear process. This might have been true when knowledge production

was firmly in Mode 1, when Bush presented his work to President Roosevelt in 1945 [25]. Increasingly a linear system fails to account for the complexity of the innovation process, new modes of knowledge production, shortening timelines between knowledge creation and innovation [26] and the network of relationships to commercialise knowledge [27, 28].

However, the importance of the national innovation systems approach is twofold. Firstly, it highlighted the importance of social capital (for example to reduce transaction costs and build trust [29]) at the heart of innovation. The second is the construction of an innovation system, based on a social construct [30], that evolves over time [28].

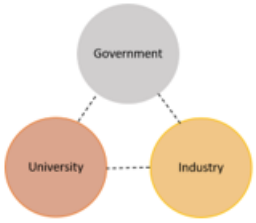
These two dynamics are the key to understanding the development of partnerships for innovation and distinguish it from previous models of innovation. Through this lens the Triple [27], Quadruple [21, 31] and Quintuple [32] Helices are an extension of, or evolution from, the national systems approach as they retain a social construct at their core but take on an evolutionary systems approach.

2.2.1 Triple Helix

The Triple Helix model [27] is a model of interactions that takes place between knowledge producers (universities), creators of economic wealth (industry) and promotors of the public interest/regulators (government). Each partner is represented by a helix, and each helix represents a sub-system connecting or interacting with the other helices in a spiral at a variety of scales (local, regional, national and super-national scale) [33]. There are several variants of the Triple Helix to represent their evolution from different economic conditions. These are briefly presented in Table 2.3. A more detailed discussion can be found in Appendix A.

A benefit of the Triple Helix model is its flexibility – where partnerships can be created and managed in a manner that is appropriate for the local circumstance [13, 34]. But the ability to adopt a different version of the Triple Helix in every context (see Table 2.4) is also a weakness as universality means that it is more of a framework than a practical expression of a process to follow to successfully commercialise knowledge [3, 35]. This issue has implications for the research presented in this thesis which is discussed further in Chapters 4 – 7.

Table 2.3 Triple helix model structures

Triple Helix structure	Diagram	Description
Triple Helix 1: Statist		Nation state encompasses academia and industry and directs relations between them
Triple Helix 2: *Laissez faire*		Separate institutional spheres with strong boundaries between them
Triple Helix 3: Overlapping or balanced		Generation of knowledge through the overlapping of institutional spheres
Triple Helix 3: Social structure		People representing their own views and interests leads to creation of new structures at intersections
Triple Helix 4: Delayed Government	Overlapping merging back to statist	Led by university and industry, but government involvement only happens later, but then takes over

2.2.2 Quadruple Helix

In recognition of the increasing universal access to knowledge and the progression from Mode 2 to Mode 3 knowledge production the addition of a fourth helix (to represent the codification of knowledge within society) to create the Quadruple Helix has been proposed [21]. The fourth helix represents a development in both the model itself as well as the structure of the model as the fourth helix does not represent an

organisation but rather the interests of society resulting from the democratisation of knowledge [21, 36].

The fourth helix represents the importance of engaging with the public to successfully achieve goals and objectives [21]. It is unclear who owns the goals, but the fourth helix is responding to the democratisation of knowledge and represents the interests of the public in a manner different to the government's ability to represent the public interest.

The introduction of a fourth helix also reflects a move in Europe towards open science and Responsible Research and Innovation [37] (see Appendix A) whereby research organisations, and businesses engage in conversations with societal stakeholders and practitioners to ensure that their proposed research direction is broadly acceptable to society. The fourth helix is argued to represent the social structure that underpins the Triple Helix [31].

2.2.3 Quintuple Helix

The Quintuple Helix adds a further helix to the Quadruple Helix. The Quintuple Helix was also proposed by Carayannis [32] arguing that it offers an analytical framework where knowledge and innovation is connected with the environment or natural environments [32]. The fifth helix is represented as a further subsystem akin to, and given equal status of, the other sub-systems: namely university, industry, government and public interest. But the equal weighting given to the environment is also the challenge of the model, as to create innovation that is sustainable requires an understanding of planetary boundaries and an understanding that what is possible locally impacts what is acceptable globally.

As there is no planetary boundary within the Quintuple Helix the issue of finite resources does not interact with decision making and does not offer an explanation as to why a Quintuple Helix model will result in innovation that is any more sustainable than the Triple or Quadruple Helix.

Table 2.4 Triple Helix outcome development

Author	Outcome sought
Leydesdorff (1996) [38]	High technology development; global knowledge economy
Etzkowitz and Leydesdorff (1995) [27]	Wealth creation
Etzkowitz and Leydesdorff (2000) [20]	New technologies (for example biotechnology and ICT))
Etzkowitz et al (2000) [28]	Improving regional or national economic performance
Etzkowitz (2003) [39]	Transition to a knowledge-based economy
Etzkowitz (2011) [40]	Technological innovation and economic development
Etzkowitz (2013) [8]	Science based innovation
Etzkowitz and Zhou (2017) [41]	Developing technologies and applied research
Cai and Etzkowitz (2020) [42]	Regional economic growth and entrepreneurship; Research

2.3 The creation of hybrid organisations

Models based on the interaction of various helices give rise to the potential for the creation of hybrid organisations where the helices cross or bridge the boundary between the organisations [27]. The rate of production and the complexity of these organisations is increasing. This issue is discussed further in Appendix A, Publications 1 and 2 and Chapter 6.

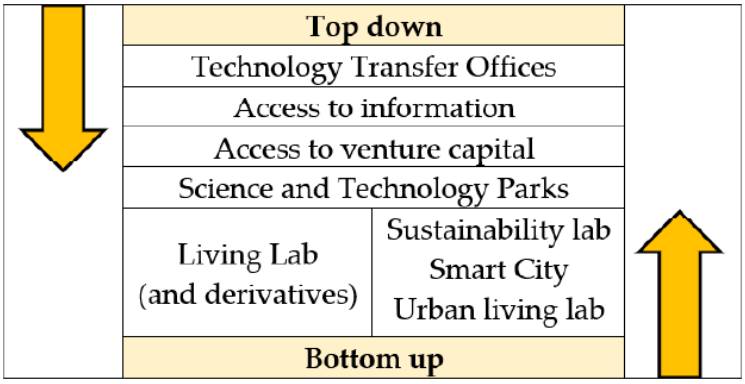
The deepening of the knowledge-based economy is affecting how all partners interact - university, industry and government - but also how consumers and citizens interact with other partners in the innovation ecosystem [43]. This has created new power dynamics and new opportunities for individualised partnerships [44] at different scales [45, 46].

In the literature these hybrid organisations, or intermediaries for innovation, are presented as the result of a top-down, or bottom-up, initiative within the partnership (see Table 2.5). Table 2.5 presents a range of organisational responses taken to commercialise knowledge. Top-down responses are presented as being the result of

management decision making whereas the initiative for bottom-up intermediaries is less specific [41] but comes from within the organisation (Publication 1).

Publication 1 (see Section 4.1) presented an addition to the top-down/bottom-up hypothesis. This proposal was for an evolution in the development of the intermediaries for innovation that was based on both top-down/bottom-up initiatives but also on the ability to create different sorts of organisations due to exogenous factors. In doing so it suggests a link between the creation of partnerships for innovation at the university-industry-government nexus and the changes in the mode of knowledge production as well as the deepening of the globalisation of the economy. This is discussed in greater detail in Section 4.1 and developed further in Chapter 7.

Table 2.5 Innovation intermediaries in society (Publication 1)



2.4 Partnerships delivering economic, social and environmental outcomes

There is a thin vein of research concerning the development of partnerships for innovation to deliver low carbon or sustainable innovation. Publication 1 showed that those partnerships that do so are living labs and, in this synthesis of the literature review, represent a bottom-up typology. The literature does not offer insights into why top-down structures do not cater for sustainable innovation but rather focus on economic development with the consequent benefits afforded to economic agents. This issue is discussed in greater detail in Section 4.1, Appendix A and Appendix B.1 – Publication 1.

2.5 Developing expertise in partnership development

The importance of commercialising knowledge as a route to economic growth is widely recognised in the literature [12] and by international development organisations

[6] and came to the fore particularly after the 2008 financial crisis due to the potential to create new jobs [47] and to harness the next wave of economic prosperity [5].

Australia's National Innovation and Science Agenda (NISA) was presented in 2015 and created an agenda to exploit the economic opportunities presented by innovation to drive economic growth and maintain standards of living [5]. The Agenda presented four pillars to support innovation policy – one of those pillars was collaboration.

In 2014, the rate of collaboration between Australian universities and industry was the lowest in the OECD [5, 48] and remained weak in 2021 [49]. Australian industry is also weak at collaborating with other businesses or suppliers for innovation with 25% of those who do collaborate doing so with another organisation within their ownership structure [50]. Business collaboration with publicly funded research is limited, standing at 2% of patent applications [50]. However, collaboration to deliver innovation added $10.8bn to the Australian economy in 2018 and generated 30,000 jobs, although this is 30% lower than achieved in USA and Israel [51].

The relative weakness in collaboration stands in contrast to public university research output of which 90% is at or above world standard [51] ranking Australia at 23 in the world innovation index [52].

Australia performs well in knowledge creation but poorly in translating that knowledge into new products and services [49]. This weakness has been recognised by Innovation and Science Australia [53] who in 2017, made improving the collaboration between universities and industry as one of their five imperatives [54].

Chapter 3 Methodology

This Chapter outlines the methodology utilised for this thesis as well as the data collection and analysis methods.

3.1 Research methodology

This research adopted a mixed methods approach combining a systematic literature review, narrative literature review, critical analysis, thematic analysis, inductive reasoning, case study and interviews. The method utilised for each publication is outlined in Table 3.1 and discussed in Sections 3.2.1 to 3.2.4.

Table 3.1 Research methods reported in the publications

Publication number	Publication	Method
1	A systematic literature review of partnership development at the university-industry-government nexus	Systematic Literature Review including PRISMA methodology [55] Critical assessment of outputs through articulated, attributed and emergent data [56]
2	Business models for sustainability in living labs	Case study assessment of narrative business cases Inductive reasoning
3	If living labs are the answer – what's the question?	Narrative review and qualitative inductive reasoning developing initial theoretical framework for research
5	A study of Australian universities' collective response to climate science.	Qualitative and quantitative review of universities' response to climate science based on detailed deconstruction of annual reports, mission statements and corporate strategies for all Australian universities Document analysis consisting of detailed textual and balance sheet analysis
5	Happy homes – the relationship between homes and mental wellbeing	Narrative review Inductive reasoning Qualitative business case development
6	*Unpublished:* Interviews for campus development	Case study of the development of student accommodation.
7	*Unpublished* literature review	Narrative literature review

Mixed methods research has been referred to as the third research paradigm after quantitative and qualitative research [57] and this research is based on a mixed methods approach. The research design is such that it deductively analyses the theory and then applies it to case studies and in turn refines the theory in the light of the findings. It follows the mixed methods tradition with a combination of data and data sources that are interdependent to develop an outcome that is integrative [58]. The sources of data used in the publications, and the heretofore unpublished data presented in this thesis meet Bazeley's [58] test of being interdependent, mutually informing and used for a common purpose.

The data used is derived from many sources where qualitative data weighs more heavily in the design and execution of the research. Qualitative research refers to a wide variety of approaches to and study of natural social life and the outputs include new insights and understandings of social complexity and the evaluation of policies and programs. Hence qualitative research is grounded in the non-fictional realm of social reality [59]. But quantitative data has also been used to test assumptions and findings.

There is a definitional debate in the literature about what constitutes a mixed methods approach. Many academics argue that mixed means a mixture of qualitative and quantitative data (for example see [57]). This thesis meets Creamer's [60] test of using qualitative and quantitative data and integrating them in a meaningful way.

However, there is a parallel approach that posits the important point is how the data is used and integrated and that a variety of data sources is more important than a simple split between quantitative and qualitative data (for example see [58]).

This thesis draws inspiration from both approaches to the methodology and it draws strength from the mixture of qualitative and quantitative data sources which are integrated deriving gains in knowledge when different types of data are actively and systematically engaged.

3.2 Research design

This research was designed to remove the sequentiality of data collection but to keep a clear focus on the research outcome. The research design was integrative and reflexive with a focus on the research outcome as well as research process. This has led to a degree of real author angst but also unexpected creativity, energy and clarity which

in turn has led to a discursive and analytical assessment of the theoretical underpinnings to the Triple, Quadruple and Quintuple helix, informed by findings at various stages of gestation, which has resulted in a significantly stronger and more fundamental contribution to society's knowledge which is outlined in Chapter 6 and Chapter 7.

This reflexivity has been strengthened by the mixed methods approach[1] to this research since different forms of data, at different stages have impacted in a non-sequential yet focussed and meaningful way to the development of the final research outcomes.

3.2.1 Systematic literature review – Publication 1, Appendix B.1

Systematic literature reviews (SLR) originated in health studies but are now used in the social and engineering sciences. They are also consistent with the mixed methods approach of this thesis as they take qualitative and quantitative findings and integrate them in a meaningful manner [61]. The SLR offers a methodology to interrogate a body of data in a manner that is repeatable, and evidence based [62] to produce valid and reliable results [63].

A systematic literature review "is a review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyse data from the studies that are included in the review" [55]. In 2005 an international meeting endorsed the use of Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) for use in SLRs [64]. PRISMA focuses author attention on the way to ensure transparent and complete reporting of data in SLRs [64]. PRISMA therefore helps to manage bias in the selection of articles for inclusion and the reporting of data in SLRs [55]. PRISMA is deemed applicable to all SLRs and not just ones carried out in health [55]. The SLR undertaken for this research complies with the PRISMA statement [64].

3.2.1.1 Discussion of the analysis of latent qualitative data

The SLR is a way of making sense of a large body of data in a manner that manages author bias with regard to the selection of articles [62]. However, this still leaves the interpretation of the results open to author bias. To further manage author bias in the interpretation of the search results a method developed by Massey [56], initially proposed

[1] See Bazeley (2015) or Creamer (2018) for a fuller discussion of the benefits of integrative data in mixed methods research

for use in interpreting the results from focus groups, was adopted. Using this process, a more transparent and repeatable process for the interpretation of results was developed [56].

In concert with Massey [56] the three levels of data should be viewed as a hierarchy, where the potential for bias is inverted according to its position in the hierarchy with articulated data being subject to least bias (and therefore most repeatable) whereas attributional and emergent data are the least transparent due to the necessary engagement with the SLR authors' views and experiences. It is important to note that bias is not eliminated, but it is minimised and managed to increase the replicability of the work. It is also important to note that the quality of findings increase from articulated (low) to attributed (medium) to emergent (high).

The use of Massey's [56] methodology in an SLR has not been done before. There were significant, and somewhat unexpected benefits that came out of using the process (see below). It should be noted however that it did create a significant extra burden of work, but the results were sufficiently strong to prove its usefulness. The key benefits were:

- The analysis of the attributional data (i.e., the theoretical underpinning for each article) provided insights into the epistemological foundation for the work. This foundation was exposed due to the methodology followed and is a clear benefit in adoption. In this SLR it was demonstrated that the partnerships for innovation were looked at through an economic lens, which contributed to a key finding. This benefit was unexpected but has proved to add real insights into the study's conclusions.
- The section on emergent data provided a useful discussion of findings and emerging hypotheses in a manner that was discreet and did not interfere with the presentation of the observable data. This benefit was unexpected but has proved to be very useful.

The use of the methodology adapted for SLRs [12], whilst involved and time-consuming delivers tangible benefits to the study and might be adopted more widely.

3.2.2 Case study – Publication 2, Appendix B.2

This case study involved an in-depth analysis of business cases for four active sustainability living labs (known as SusLabs) which were part of the SusLab Northwest Europe network (SusLabNWE). Case study research methodology is broadly based with few limitations in terms of what is being studied [65]. The case study in this thesis is defined as a cross case study [66] or multiple-case study [67].

Table 3.2 Modification of Massey's [56] model for thematic analysis of latent data

Levels of data	Massey definition [56]	Revised definition	Source of data	Potential for bias	Quality of findings
Articulated data	Information that is expressed in response to, or specifically addresses the questions posed	Information that is stated directly by the original research authors as the result of their research. this is the original author's statement of results achieved and reported in the article.	Data is articulated by one or more study in the SLR	Lowest	Low
Attributional data	Comments and discussion that relate to *a priori* hypotheses or theories that the evaluator brings to the study	unchanged	Data is a co-location of ideas from 2 or more articles and is supported by extant models and theories	Medium	Medium
Emergent data	Information that contributes to new insights and hypothesis formulation and is the unanticipated product of individual comments and exchanges amongst group members.	Information that contributes to new insights and hypothesis formulation and is the unanticipated product of connections arising from different articles	Data that is the result of the consideration of articulated and attributional data. It is not necessarily supported by an extant body of work	Highest	High

The case study involved a detailed and intensive study of the business cases for four active sustainability living labs in northwest Europe (see Table 3.3). The business cases reviewed were done so at a single point in time to understand how each SusLab was approaching the engagement of partners and their strategy for longer term viability. The cases selected were sustainability living labs which were primarily focused on reducing energy consumption and increasing energy efficiency.

In the extant literature the focus on partnerships to deliver sustainable innovation is scarce (Publication 1, [12, 14]) hence these four viable sustainability living labs provided an opportunity to look in depth at business case development to deliver economic, social and environmental outcomes, as well as to understand what motivated the development of each business case and then draw conclusions. It is not clear if the four business cases are a bounded unit or representative of the field [66] – this is difficult to judge in such a confined and niche field.

Table 3.3 Case study participants

Organisation	**Business model**
HSB Living Lab, Sweden	Knowledge to business and business to business
SusLab NRW, Germany	Business to Business and Business to consumer
SusLab Living Lab, UK	Demonstration of concept
Concept House Village, Netherlands	Sponsorship

However, when compared to the wider living lab literature these four cases represent "cases that are different on all independent variable except the one of interest to the researcher" and as such they provide a strong basis for generalisation [68]. But what is more apparent is that studying the four cases has led to the development of theories and causation that are congruent to the mixed methods approach of this thesis and the evidence is used in the conclusions drawn in Chapter 6 and Chapter 7.

3.2.3 Narrative review and inductive reasoning – Publications 3 and 5, Appendix B.3 and B.5

Publication 3 is explorative in nature. It was written to explore some of the barriers to the adoption of best practice in partnership development. It was designed to explore the performance of particularly Australian universities in partnering with industry and it was also designed to start the process of thinking about how to create innovation at the university-industry-government nexus that supports the delivery of sustainable development

Publication 3 was transdisciplinary by design and inspired by behavioural economics and specifically theories developed to explain how humans think and make decisions [69] to see if these could be applied to how organisations make

decisions. Publication 3 illustrates that there is a rich seam of work in this space (in the footsteps of *The ecology of commerce* [70]) but that ultimately, although fascinating and potentially mould breaking, decision making is outside the remit of this thesis and is for future research.

Publication 5 was designed to establish the forms of issues that a university student accommodation construction project could address in partnership with industry and government. It was designed as a narrative literature review to explore the issues of mental health and accommodation to identify what forms of design interventions are available to either stabilise or improve mental health.

3.2.4 Quantitative data collection and analysis – Publication 4, Appendix B.4

The results of semi-structured interviews (see Chapter 5) highlighted the difficulty practitioners were having in managing a complex process with interrelated but competing themes. To see if this was an issue specific to the Greater Curtin project or a more generic issue, research was undertaken on Australian universities collective response to climate science.

There are 43 Universities in Australia. All Australian university websites were accessed between 18 – 20 November 2016 to download their 2015 annual report and financial statements and their forward-looking corporate strategies (dates ranging up to 2025). Also, all government/university performance agreements (known as Mission Based Compacts) were accessed from the Department of Education and Training website. A limit of 30 minutes was allocated to each university to find and download the data. Where the data was unavailable online (either not found or not published) it was requested by email.

All available annual reports and strategies were read and the public commitments in those reports (for example published statements, targets and performance) to partnership and adopting research were recorded and tabulated. Research on climate change was taken as the example for adoption of research due to the agreed status of the science [71], and the applicability of it to campus development (and therefore to capital investment in campus projects).

The documents were also searched through keywords (carbon, sustainable, greenhouse, climate change and variants) to understand the importance of sustainability and climate change for each university. They were also searched to understand the importance of collaboration within the university, to the university (words searched were cross-, inter-, multi-, trans-disciplinary and variants) as well as externally with industry, society and government.

Each University's capital spend, committed for 2016[2], was recorded to understand the potential of the sector to use their own capital spend to adopt and commercialise their own research (for example a university with no forecast capital spend would find it more difficult to integrate teaching and research into campus development).

Due to the incomplete nature of performance data within the university publications, publicly available performance data was accessed to develop an indicative understanding of the rate of change of emissions from Australian universities and thereby to understand their success in translating research into impact.

3.2.5 Case study: semi structured interviews - Chapter 5

Chapter 5 details the results of a series of semi-structured interviews, undertaken in 2016 with practitioners. The interviews explored the practitioners' views on the process of integrating education and research outcomes throughout the design and construction process for a university student accommodation project. Interviews were semi-structured consisting of 10 meta-questions (see Table 3.4) with the opportunity for the interviewee and interviewer to then discuss issues that arose or needed further elucidation. Interviewees were chosen to represent a cross section of senior academics, business managers and consultants (see Figure 3.1) to test hypotheses developed for Publications 4 and 5. Interviews were conducted in Autumn 2016 and lasted for approximately one hour. All interviews were recorded using *Livescribe* and then manually transcribed. To protect individual's privacy all participants have been anonymised. The results of the interviews were then coded and analysed. The themes and associated nodes identified in the thematic analysis are set out in Table 3.5.

[2] All annual reports detail money spent during the past year. They are also required to report on capital expenditure for the forthcoming 12 months and 5 years. Hence 2015 annual report contain data for 2016.

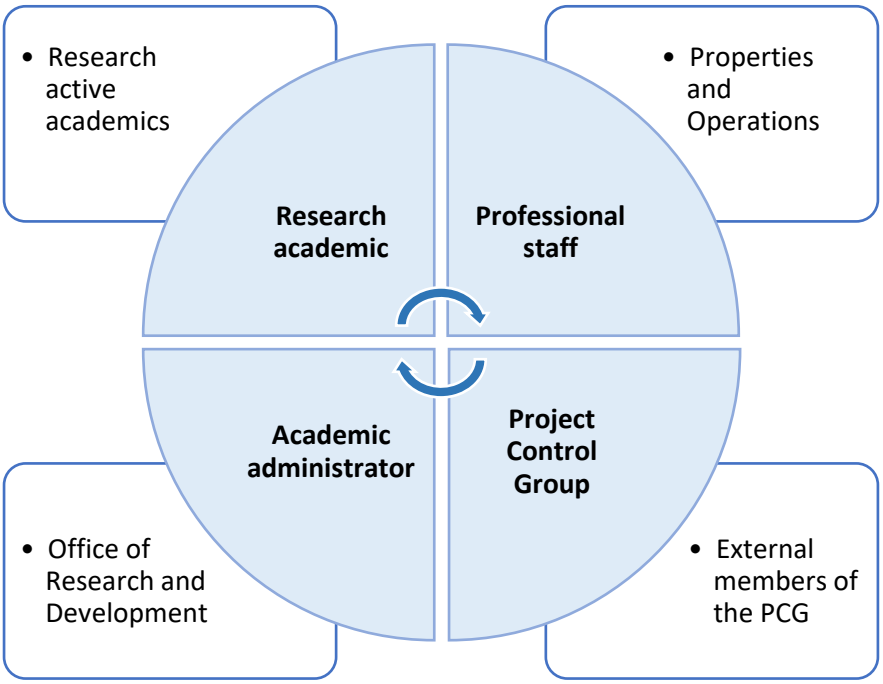
Table 3.4 Meta questions influencing semi structured interviews

	Question
1	How has innovation, leadership and teaching and research excellence been planned into Stage One?
2	Can you identify any specific examples of Innovation, Leadership, Teaching, Research that have been included in the EOI process?
3	How much has Curtin spent so far developing the Stage One proposal?
4	How much of this is for professional services (by which I mean consultancy advice)?
5	How many of Curtin's academics have been consulted on the development of the Stage One proposals?
6	Can you identify any specific examples of Innovation, Leadership, Teaching, Research that have been achieved to date?
7	How much has Curtin budgeted to spend by early 2017?
8	Can you identify any specific examples of Innovation, Leadership, Teaching, Research that are intended to be delivered by early 2017 and 2019?
9	Can you identify the teaching and research outcomes associated with that expenditure?
10	How does the activity and the planned activity demonstrate leadership by Curtin?

Table 3.5 Themes and associated nodes identified in the thematic analysis

Theme	**Node**
Leadership	Using exemplars
	Developing teams
Developing opportunity	Integrating research
	Integrating teaching
	Outreach
Risk management	Learning from others
	Learning by doing
Developing partnerships	Business to business
	Academic to business
Communication	Knowledge
	Participation
	Ease of engagement

Figure 3.1 Interviewee's involvement in student accommodation project



The purpose of the interviews was to test the findings of Publication 5 and to understand how deeply embedded research, teaching, leadership and innovation were into the accommodation project. The interviews also went deeper to understand the extent to which the project was being used to create partnerships for innovation and collaboration, either in practice or in future stages of development.

These data have not been previously published but they are the third part of a triptych of publications (Publications 4, 5 and Chapter 5) exploring the factors that promote or limit low carbon innovation at the university-industry-government nexus (see Sections 4.4. and 4.5 for a detailed discussion).

Chapter 4 Publication results and discussion

This Chapter provides a summary of each publication and thereby mapping a progression in thinking and the development of the research evidence for the thesis. Table 4.1 summarises how the published and unpublished work address the research questions.

Table 4.1 Summary of how publications address the research questions

Sub-questions	**Objectives**	**Associated publications**
Which partnership models at the UIG nexus have been successful in delivering innovation?	To identify the development of partnership models to create best practice partnerships To identify partnership structures that are being used to deliver a low carbon future.	**Publication 1**: A systematic literature review of partnership development at the university-industry-government nexus Published, peer reviewed article
Which partnership models at the UIG nexus have been successful in delivering low carbon and/or sustainable innovation?	To identify best practice in business case development in partnerships at the UIG nexus	**Publication 1**: A systematic literature review of partnership development at the university-industry-government nexus **Publication 2**: Business models for sustainability in living labs Published, peer reviewed book chapter
What factors promote or limit partnership development for a low carbon future?	To identify issues that prevent effective partnership creation	**Publication 3**: If living labs are the answer what is the problem? Published, peer reviewed article
How can Australian universities become more effective at partnering with Government and industry to drive a low carbon future?	To identify Australian universities' performance in partnering with industry and Government; To identify the opportunities for universities to work with business, or Government in partnership; To identify universities' performance in adopting low carbon policies	**Publication 4**: A study of Australian universities' collective response to climate science Published, peer reviewed article **Publication 5**: Happy homes – the relationship between homes and mental wellbeing. Published, peer reviewed article
How can Australian universities become more effective at partnering with government and industry to drive a low carbon future?	To identify the process to develop a construction project to deliver student accommodation	**Unpublished**: Case study of the development of student accommodation. See Chapter 5

The Chapter is arranged to provide a summary of the paper, the findings associated with each paper; a discussion of the findings and then concluding remarks which place the papers in the wider context of this exegesis. The publications have been reproduced in full in Appendix B.1 to B.5.

4.1 A systematic literature review of partnership development at the university-industry-government nexus

This article, Publication 1, was published in a peer reviewed journal (Appendix B.1). It directly addresses sub-question 1 and includes a contribution to sub-question 2 (see Table 4.1).

- Sub question-1: Which partnership models at the UIG nexus have been successful in delivering innovation?
- Sub question-2: Which partnership models at the UIG nexus have been successful in delivering low carbon and/or sustainable innovation?

4.1.1 Summary of findings

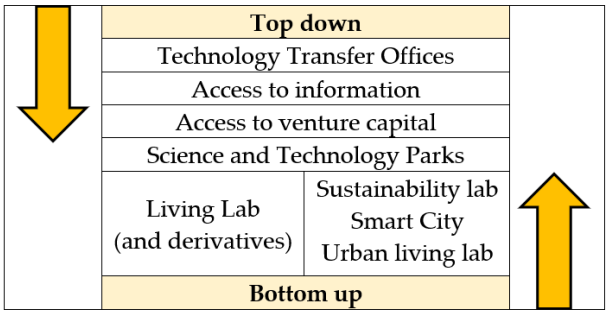
Publication 1 has made the following contribution to the theory of partnership development at the university-industry-government nexus.

- Builds on top-down/bottom-up analysis discussed in the literature and demonstrates that the evolution of partnerships for innovation are driven by factors within the partnership but also by factors external to the partnership;
- Describes 3 stages in the evolution of partnerships for innovation, which can be concurrent: namely the development of on-campus structures; campus adjacent structures and living labs;
- Finds only living labs (and derivatives) tackle economic and social issues; a smaller subset tackle economic, social and environmental issues;
- Due to the adaption of Massey's methodology [56] for analysis of latent data (see Section 3.2.1.1), Publication 1 demonstrates that the majority of research in the literature is grounded in economic theories; and
- Development of a hypothesis linking evolution of partnerships for innovation, globalisation of economy, society and environment and changes in modes of knowledge production.

4.1.2 Partnership development at the university-industry-government nexus

Publication 1 reveals that the innovation intermediaries created by university, industry and government are created through an internal dynamic, and these are either management led (top-down) or led by an entrepreneurial individual or group (bottom-up) [34, 41]. These types of intermediaries for innovation, as identified in the literature, are shown in Figure 4.1 (Publication 1).

Figure 4.1 Innovation intermediaries at the university-industry-government nexus



It is clear from the literature that the deepening knowledge-based economy is affecting not only how universities, industry and government interact, but also how consumers and citizens [43] interact with other partners in the innovation ecosystem. The pace of change affects all sectors of society (university, industry, government as well as citizens), and this dynamic relationship is rapidly changing, which is leading to new forms of intermediaries that are highly individualized [44]. This, in turn, leads to the opportunity for innovation at different scales and under differing dynamics and delivering different outcomes [46, 72].

Various forms of intermediaries are being created because of decisions made within the partnership, but also being facilitated by external opportunities and stimuli (exogenous factors). It is this overlay of externally changing dynamics that has led to new forms of intermediaries for innovation emerging [73] and that are being led by, or include, different actors [74] or different power dynamics and approaches [72, 75].

Additionally, new models for innovation are being adopted by different sectors—including the public sector [76] or cities [77]. It is this change in dynamics, structure and power relationships that is leading to the nascent creation of innovation

that is seeking to deliver economic, social and environmental enhancements at the same time (Publication 2 [78]).

These external stimuli (the deepening of the knowledge economy; increasing globalisation of the access to the internet) has led to the description of an evolution in partnerships for innovation at the university-industry-government nexus. This is detailed in full in Publication 1 (see Appendix B.1). The research shows the temporal evolution of three types of structures to promote partnership development and the commercialisation of knowledge:

- On campus structures. These are typically created as a management response to encourage greater partnership between the university and industry or government. The intervention ranges from access to university library facilities [79], to the creation of posts such as knowledge transfer officers [80] or academic liaison officers [81], or the creation of space for incubators [82]
- Campus adjacent structures. This involves the creation of science and technology parks (STPs) (and derivatives) adjacent, or close to a university, or cluster of universities. This process started in North America [7] and was adopted in the UK and Europe [83-85]. There is much debate about the efficacy of STPs [86] but Publication 1 does reveal the STP inhabitants place value on informal links with universities [79, 87, 88].
- Development of living labs. Living labs are partnership structures focussed on user engagement and open innovation [89]. The impetus for the development and increasing adoption of living labs was the ability for a range of stakeholders to become involved in the process of innovation [90].

Publication 1 also revealed that much of the research undertaken into partnerships for innovation is, epistemologically, through the following three broad lenses:

- Economic theories: most papers (over 100 of the 132 reviewed in Publication 1) looked at the issue of partnerships for innovation with an economic theoretical underpinning analysed through theories of innovation, economic geography, planning and transitions.
- Social theories: the main focus in the social theories was how individuals interact with or contribute to innovation.

- Theories of learning: this was a shallow vein of work but there were elements looking to see how innovation could be used to deliver learning to students, and how organisations can learn by doing.

Publication 1 also revealed, in concert with other studies (for example see [14]) that there was limited research looking into the delivery of innovation that seeks to balance and integrate economic, social and environmental interests at the same time. Further it revealed that the only partnership structures, as identified in Publication 1, to do so were living labs and their derivatives. This is discussed further in Section 6.1.1.

4.1.3 Discussion

Publication 1 revealed several interesting insights. The first was the finding that factors exogenous to the partnership were driving partnership development whilst the literature has viewed the development of new partnership structures as the result of endogenous factors (that is due to decisions taken within the partnership). This finding is new to the literature and led to the development of potentially sequential creation of partnership structures at the university-industry-government nexus. The temporal nature of these partnerships is discussed in detail in Section 6.1.1. and developed in Chapter 7.

The second finding is that, in Publication 1, the only partnership structure to seek to deliver sustainable outcomes is the living lab (and its derivatives). The literature does not reveal why the living lab structure is the preferred structure to deal with sustainable development. This too is discussed further in Section 6.1.1. There are two hypotheses: one is that it is because the research undertaken is driven through economic theories with limited articles being underpinned with a sustainable perspective; the other is that the living lab approach is based on user engagement and open innovation which allows greater visibility to, and expression of, a community of interests in low carbon transition and sustainable development.

4.1.4 Progression in research findings

The use of the adapted Massey methodology [56] to augment the SLR (PRISMA) [55] methodology was powerful (see Section 3.2.1.1). Analysis of attributed data led to the finding that the majority of the research presented for analysis through the SLR methodology was grounded in economic theories.

Discussion of the emergent data led to the development of a hypothesis that links the evolution of partnerships for innovation at the university-industry-government nexus to the globalisation of the economy, society and environment as well as the changing modes of knowledge production. This is set out in Table 4.2 developed further in Section 6.2 and progressed to the presentation of a metastructure in Chapter 7.

The limited focus in the literature on partnerships for low carbon innovation and business cases to develop low carbon partnerships is also addressed in Publication 2.

Table 4.2 Hypothesis of current relationship between partnerships, globalisation and modes of knowledge production

Evolution of partnerships for innovation	**Potential partnership response to trends in globalisation**			**Mode of knowledge production**
On campus	Economy			Modes 1 and 2
Campus adjacent		Society		Modes 2 and 3
Living labs			Environment	Mode 3

4.2 Business models for sustainability in living labs

Publication 2 is a book chapter with seven co-authors (see Appendix B.2). It directly addresses sub-question 2 and includes a contribution to sub-question 1.

- Sub-question 2: Which partnership models at the UIG nexus have been successful in delivering low carbon and/or sustainable innovation?
- Sub-question 1: Which partnership models at the UIG nexus have been successful in delivering innovation?

4.2.1 Summary of findings

Publication 1 (see Section 4.1) showed that the innovation partnership structure to deliver economic, social and environmental outcomes at the same time was the living lab. Therefore, the objective of this publication was to look at the development of business cases for four sustainability living labs (SusLabs) to understand the drivers of their development. The four SusLabs were focussed on the development of energy

efficient products, services or systems but all had different businesses cases. Publication 2 sought to understand the reasons for this difference.

Publication 2 has made the following contribution to the theory of partnership development at the university-industry-government nexus:

- Each business case was different due to the impact of three factors:
    - The principles or purposes underpinning the SusLab's creation;
    - The response of each entity to pressures or opportunities they faced during operation; and
    - The response to internal or external opportunities which meant the business cases evolved over time
- The article shows how the Triple Helix model can be implemented locally and can be used in partnerships for innovation that seek to deliver innovation consistent with sustainable development; it shows how path dependence theory helps to understand the decision-making process to develop business cases; and it shows the value members of the European Interreg project (SusLabNWE) placed in being part of a wider consortium to assist with learning from experience and from doing.

4.2.2 Business case development for low carbon innovation

The book chapter had three significant findings. Firstly, business cases were different because although each SusLab was focussed on energy efficiency they each had a different founding principle or purpose. The purpose was either development of products, services or systems but also there was a focus on knowledge creation through research and business to business development. Further detail is provided in Table 4.3.

Table 4.3 Summary of individual SusLab purpose

SusLab	Purpose
HSB Living Lab	Attracting companies who will commit to research and development for their own and societal interest
SusLab NRW	Testing products and services in a real home environment
SusLab Living Lab in London	Procured projects to demonstrate potential of collaboration
Concept House Village	Procured projects to demonstrate potential of collaboration. Students involved in design and build

Secondly the gestation of each SusLab was different and arose due to different internal or external pressures and/or opportunities and this meant that each business model evolved differently. A summary is provided in Table 4.4.

Table 4.4 Summary of each SusLab's business case

SusLab	**Business model**
HSB Living Lab	Knowledge to business and business to business
SusLab NRW	Business to business and business to consumers
SusLab, London	Demonstration project
Concept House Village	Sponsorship

Thirdly each business case, like each SusLab, is evolving. Neither each SusLab nor their associated business case is static but changes as opportunities arise. The change can be iterative (for example SusLab NWR identified a new stream of income and was rethinking its business case as a result). The changes can also be more fundamental. For example, Concept House Village was created with a backdrop of public funding, but its new business model is focussed on being independent of public funding and to accelerate the real market application of its prototyping with a view to becoming a regional focal point for sustainable building.

4.2.3 Discussion

The study of the individual cases is interesting and confirms the importance of three extant theories or models. It shows how the Triple Helix model [27] can be implemented to benefit consumers and how the model can be applied to innovation driving sustainable outcomes. It demonstrates that path dependence theory is relevant and does influence decision making, though not by repeating the same decisions, but by using the same prompts to help make decisions (this issue is further considered in Section 5.4). Further it demonstrates the value of co-creation and including end users, for product development.

But the other benefit of the SusLabNWE consortium is unexpected, and that is the value each partner places on being part of the network. These benefits are set out in Table 4.5. This is a finding that is shared with Publication 1 (discussed in Section 4.1.3)

which found that informal linkages with a science and technology park are important to park inhabitants. In Publication 1 such informal connections ranged from social activities to assistance with business processes (like human resources) which whilst not mission critical was important none the less. It appears that all SusLab partners valued learning by doing but also learning from other people's experiences.

Table 4.5 SusLabNWE—informal value to partners in the SusLabs of the Triple Helix

Value	**Benefit**
Communications	Document ongoing work on SusLab website, including findings from HSB Living Lab, and the Living Lab at the Institute of Sustainability Finalise SusLab book and promote methods at scientific and professional forums as well as at network events
Academic	Work with network to share and co-develop new SusLab methodologies Publication of results and methodology in academic journals Continue to develop SusLab sensor tool kit to support new work Continue to develop the SusLab tools such that the toolkit can be easily deployed in the field by sustainable building researchers and practitioners Each SusLab has a measuring and monitoring element and all four can be connected to a single data store and analysis tool to enhance rigour and ensure learnings are shared
Outreach	Maintain network of living labs linked to SusLab website Link SusLab work to regional networks Leverage SusLab network combined with new partners to develop new joint projects Value/weight to partners from increased potential to attract further funding (public and private) for SusLab and product development Enhanced business and academic brand value

4.2.4 Progression in research findings

The findings in this publication are consistent with the findings of Publication 1 (see Section 4.1.1) namely that:

- The Triple Helix model is relevant to a range of situations including sustainable innovation;
- Co-creation and open innovation are central to the SusLab approach;
- Being part of a community of interest is important;
- Learning by doing can be augmented by learning from other's experience;

- The factors influencing decisions are endogenous and exogenous to the partnership; and
- Publication 2 has also shown the importance of path dependence for decision making and the potential to learn from other's experience as well as by doing (this is addressed in Publication 4 see Section 4.4.2 as well as Section 5.4). There is a clear link between the expression of path dependency and the endogenous/exogenous factors affecting partnership creation presented in Publication 1.

A transdisciplinary attempt to tackle the issue of decision making, rather that the influences on the decision is included in Publication 3 (Section 4.3 and Appendix B.3: Publication 3) but as discussed in the Methods (see Section 3.2.3), decision making, rather than factors that impact on decisions, falls outside the remit of this thesis.

4.3 If living labs are the answer what is the question?

This article, Publication 3, was published in a peer reviewed conference proceedings (Appendix B.3). It directly addresses sub-question 3.

- Sub-question 3: What are the factors that promote or limit partnership development for a low carbon future?

This publication sought to understand the performance of Australian universities in partnering for innovation as well as the performance of business in partnering with universities to commercialise research. It sought to develop key themes in the research program.

4.3.1 Summary of findings

Publication 3 has made the following contribution to the theory of partnership development at the university-industry-government nexus:

- Australian universities are weak, when compared to OECD counterparts, at partnering with industry for innovation;
- Industry is weak at partnering with Australian universities, as well as customers and suppliers;
- Universities do not make effective use of their campuses to drive partnership development;

- The rate of external change makes partnership development complex and uncertain;
- There is little evidence of the development of innovation partnerships to drive sustainable innovation at scale; and
- Proposed that SDGs should be used as the framework to drive partnerships at the university-industry-government nexus.

4.3.2 Partnership development for low carbon innovation

Continuing the theme from Publication 2 (see above and Appendix B.2: Publication 2), Publication 3 considered different forms of exogenous change detailed in the foresight literature. As such it continued to investigate the consequences for the economy and society of the further deepening of the knowledge-based economy and the likely impact on future employment prospects (where future jobs will be increasingly skill or knowledge based) and the consequent impact on wider society. It also looked at the globalisation of the environment and the continued vexed issue of the "un-managed commons" [91] and the impact of environmental change for society and the economy.

Publication 3 sought to develop the research finding in Publication 2 (see Section 0) about the importance of path dependency to decision making and to look at how organisations institute change. The paper, ultimately unsuccessfully, sought to link human judgement and decision making [69] to an organisational setting, an issue further discussed in Section 8.3.

This publication showed that Australian universities were weaker than their OECD counterparts at partnering with industry to collaborate for innovation [5, 48]. It also revealed that even though Australian industry funds public research in universities at a level that is higher than the OECD average, collectively Australian industry is also generally weak at collaborating with universities, customers and suppliers for innovation [48].

Australian universities and Australian business have a complex relationship in terms of how they collaborate with each other for research and innovation, and this is set out in Table 4.6 which is reproduced from Publication 3.

Table 4.6 Collaboration between Australian universities and business

	Industry	Universities	Customers/ students	Suppliers	Use foresight	Research user?
Industry	Collaboration between industry for innovation is weak and localised [92]	Industry fund universities to undertake research at level greater than the OECD and EU28 average.[48]	Industry is weak at collaborating for innovation with its customers [93]	Industry is weak at collaborating for innovation with its suppliers [93]	Industry weak at using strategic foresight [94]	User, and active funder of research [48]
University	Collaboration for innovation is amongst the worst in the OECD [48]	Universities are good at collaborating with universities [95]	Investment by universities and students/ alumni is the focus of increased attention (pers comm)	No evidence of universities collaborating with suppliers for innovation	Unclear as to whether universities use (rather than just research) foresight (although they do research scenarios)	Unclear if universities use the research they produce (see section 4.3)

4.3.3 Discussion

This paper contributed further to the development of thinking regarding factors external to the partnership and their impact on partnership development. The changing economic, social and environmental orbit is impacting universities, industry and government individually and collectively and this effect on collaboration needs to be further considered.

This complexity (as also detailed in Publication 1) of evolving environment means that the development of partnerships between universities, industry and government is fraught with complexity as the rate of change in the broader environment within which they operate is increasing and becoming increasingly complex (Publication 1). It also suggests that partnerships will struggle to adapt due to the impact of making decisions based on previous similar decisions (this issue of path dependency is addressed in Section 5.4).

This complex environment also provides a potential hypothesis to be tested into why partnerships for economic, social and environmental innovation happen predominantly in living lab arrangements (see Section 4.1.2), and importantly locally. There is scant evidence from Publication 3 or from Publication 1, or 2 of such partnerships happening at genuine scale.

The lack of evidence of scale raises the important issue of how to create partnerships for innovation that will drive the delivery of sustainable development. Hawken [70] argued the market mechanism can provide the solution through competitive efficiency, and his proposal was through government intervention and Pigouvian tax where the cost structure is such that the totality of external costs is considered within the marketplace. This would then drive the delivery of social and environmentally optimal development.

Publication 3 made a different proposal (which was not available to Hawken [70]), and that is the sustainable development goals should guide the delivery of partnerships for innovation. The SDGs are the shared expression of what the global collective is seeking to deliver for the global citizen and could be used to drive partnerships for innovation at the university-industry-government nexus. This issue is further considered in Chapter 6 and Chapter 7.

Publication 3 also raised the issue of how universities in particular use resources available to them to further teaching and research outcomes (Mission 1 and 2) as well as engagement (Mission 3). This started the process of thinking about the potential of campus re-development to focus on institutional settings to drive all three missions as well as the commercialisation of knowledge in partnership with industry and government.

4.3.4 Progression in research findings

Publication 3 raised the issue of how universities can make greater use of their own infrastructure to drive partnerships for innovation. The focus on the institutional setting is addressed in a triptych of articles. Publication 4 addresses the issue of physical infrastructure; Publication 5 and Chapter 5 address the issue of how to incorporate teaching and research into the heart of such redevelopment.

As discussed above, Publication 3 sought to apply Kahneman's [69] work on human judgement and decision making to an organisational setting. This initial foray, although

unsuccessful, was intuitively and logically sound and has potential, but further work is required. It would closely align to a seam of work rooted in evolutionary, environmental and ecological economics with a strong lineage to Hawken [70], Meadows [96], Hardin [91], Boulding [97], Daly [98] and others. Although outside the remit of this thesis it is worthy of further research.

4.4 A study of Australian universities' collective response to climate science

This article, Publication 4, was published in a peer reviewed conference proceedings (Appendix B.4). It directly addresses sub-question 4.

- Sub-question 4: How can Australian universities become more effective at partnering with government and industry to drive a low carbon future?

4.4.1 Summary of findings

This publication is the first of three articles that looks at how Australian universities use their infrastructure (Publication 4) or leverage (Publication 5 and Chapter 5) to develop partnerships for innovation that are based on both the experience of implementing knowledge created and using investment in campus infrastructure to develop new knowledge. Publication 4 focuses primarily on the experience of implementing change based on knowledge; Publication 5 and Chapter 5 on using investment in campus infrastructure to develop teaching and research outcomes (TRO).

Publication 4 has made the following contribution to the theory of partnership development at the university-industry-government nexus:

- Three Australian universities committed themselves to a carbon reduction target in line with climate science;
- For the 10 Australian universities who were required to report emissions data, their emissions rose by 4.63% between 2010/11 and 2014/15;
- Together Australian universities were committed to investing over $1.5bn in capital infrastructure on their campuses in 2016;
- Eight universities (20%) committed to using their campuses as living labs, or similar, to deliver teaching and research outcomes; and
- Revealed limited evidence of universities willingness to partner with themselves (to use their campus infrastructure to drive teaching and research outcomes).

4.4.2 Developing partnerships based on experience and knowledge

Publication 2 (see Section 4.2) highlighted the importance of partnerships being able to use experience and knowledge to commercialise research. Publication 4 develops this theme by considering the experience of Australian universities at adopting and implementing climate research. The purpose of the publication was to see if universities, having developed the research into climate science and translated that research into policy proposals had experience of implementing the research on their campuses. The theory would suggest that they would then be better able to take this knowledge and experience into a partnership and become a more informed member of that partnership.

This study therefore investigated four issues. The first was how universities collectively had put in place strategies to reduce emissions in line with climate science. The second was to understand the scale of capital investment that was being undertaken, in 2016, into campus re-development. The third was to look to see what relationships universities had developed internally to link academic researchers to university administrators and finally the paper sought to understand the extent to which Australian universities collectively were prepared to use their campus as test beds for innovation.

The research, based on accounting and textual analysis of all Australian universities 2015 annual reports, mission based compacts (these are performance agreements with Government) is summarised in Section 4.4.1. Table 4.7 presents Australian universities commitment to carbon constraint.

Table 4.7 Australian universities commitments to carbon constraint

	Number of universities	**Universities**
Universities with a science-based commitment	3	7%
Universities with a carbon reduction commitment and published target	12	29%
Universities who make statements but do not provide evidence as to what success looks like	15	37%
Universities who do not mention carbon or emissions	11	27%
Total	**41**	**100%**

4.4.3 Discussion

The evidence from this study suggests that universities are not yet fully realising their potential to partner with industry based on experience. The paper reveals the following issues that need to be considered.

Australian universities invested $1.5bn in 2016 on capital infrastructure on their campuses, of this, eight universities committed to using their campuses as a living lab to develop and deliver teaching and research outcomes (Missions 1 and 2 – see Section 2.2). This means approximately $1bn of capital spending in 2016 not being explicitly linked to drive teaching and learning outcomes (see Chapter 5). One university committed to using their campus as a living lab (or equivalent) in their forward-looking strategy.

97% of climate scientists agree [71] that climate change is the result of anthropogenic emissions. In 2015, only three universities had made a commitment, in line with climate science, for an absolute reduction in carbon emissions while over 25% of universities had not mentioned carbon or emissions in the documentation analysed.

Finally, the article found limited evidence for university willingness to partner with themselves. This is an important issue as universities are being pressured into developing more effective partnerships with industry. To be an effective partner universities need to have experience and knowledge of the difficulties of implementing research.

4.4.4 Progression of research findings

Publication 4 revealed the following issues that Australian universities, as institutions, need to be cognisant of when considering their capital investment in their campuses:

- An opportunity is being lost if all infrastructure spending is not being used to drive teaching and research outcomes, and/or to showcase how to adopt research;
- Universities have developed climate science, have advocated for society to adopt science-based targets but had not developed the practical experience themselves of implementing that knowledge; and
- If universities are to become experienced, transdisciplinary and knowledgeable partners for innovation they need to become more adept at using opportunities on campus for partnership development as well as delivering teaching and research outcomes. The evidence suggests that this is not a job just for academics but rather for institutions.

These issues are further developed in Publication 5 and Chapter 5 culminating with an institutional framework to help universities, industry and government better understand the opportunities to leverage knowledge to create partnerships for innovation.

4.5 Happy Homes – the relationship between homes and mental wellbeing.

This article, Publication 5, was published in a peer reviewed conference proceedings (Appendix B.5). It directly addresses sub-question 4.

- Sub-question 4: How can Australian universities become more effective at partnering with government and industry to drive a low carbon future?

4.5.1 Summary of findings

This is the second of three publications looking to see how universities use their infrastructure (Publication 4) to leverage partnerships for innovation (Publication 5). The objective of this publication was to look at how universities could become more effective partners with industry using mental health and student accommodation as a case study to illustrate the potential to drive research and partnership through campus redevelopment. The findings from Publications 4 and 5 are developed in Chapter 5.

Publication 5 has made the following contribution to the theory of partnership development at the university-industry-government nexus:

- Found little evidence in the self-help guidance of how to maintain or promote mental health in accommodation for the mentally-well;
- Through analysis of the literature developed a series of initiatives to be tested to help maintain mental wellbeing when inside accommodation;
- Proposes that there needs to be a focus on transdisciplinary (to integrate all relevant disciplines) and translational (to test and develop practical interventions that work) research;
- Needs to be a clearer focus on the social pillar of sustainable development through meeting the needs of the building resident by changing building design to improve mental health outcomes;

- Found that there is a focus in the literature on how to use building fabric to deliver desirable policy outcomes (for example climate targets) with building users being considered after policy analysis;
- Study shows the potential benefits of undertaking transdisciplinary and translational research to create an innovative partnership for innovation at the university-industry-government nexus; and
- Identified three waves of research into mental wellbeing and proposed the impact of the home on mental wellbeing should be the fourth wave of research.

4.5.2 Co-creating partnerships based on knowledge and shared implementation.

The research was conducted through an analysis of secondary sources to identify which measures and initiatives were available to ensure that the design of student accommodation was conducive to promoting positive mental health outcomes. More specifically it was looking at how the design of the living space itself (rather than the environment within which the accommodation sits) could contribute to positive mental outcomes or prevent a decline in student mental health. One purpose of the paper was to provide up to date analysis to Curtin University's student accommodation project co-ordinator on the state of the research into student accommodation and mental health (this is discussed further in Chapter 5).

The other driver of the research was consideration of how a partnership between the university and industry could be developed to prototype and test the effectiveness of new design proposals by creating a partnership to commercialise knowledge as part of the student accommodation project. As such the research sought to develop an understanding of how an on-campus student accommodation project could be used to develop a partnership at the university-industry-government nexus.

The paper identified three phases in the development of research into mental health and mental wellbeing. These start with the control of contagion in the 1800s to an understanding that mental health is impacted by the environment in the early 1900s to deeper engagement in healthy lifestyles and quality of life in the late 1900s. Pre COVID-19, the paper proposed the impact of the home on mental wellbeing to become the fourth wave of research.

4.5.3 Discussion

There was little in the literature about what mentally healthy people can do within their homes to protect and improve their mental wellbeing (either in new, or existing homes). The focus of the literature about housing and mental health is three-fold:

- Focus on those marginalised in society (be they at the intervention end of the mental health continuum or in need of housing assistance);
- Focus on the issues that will trigger a decline in physical and/or mental health of home dwellers; and
- Focus on descriptive research (i.e., we did this and that happened) rather than translational research (i.e., translating the evidence into wider action)

The work revealed that there is little in the literature to help individuals or organisations design accommodation in a way to promote or maintain mental health outcomes in the accommodation itself for mentally healthy people. It proposed that there needed to be a focus on transdisciplinary and translational research. Transdisciplinary because the study revealed the difficulty faced in capturing all the relevant disciplines; and translational because there is a continued and evidenced need to start developing interventions that can help people in the self-help/social support end of the continuum.

Secondly, there needs to be a focus on the needs of the building user, rather than the building fabric (there was evidence of using building fabric to achieve governmental goals like reducing emissions).

Thirdly, there needs to be a clearer focus on integrating the social pillar of sustainable development into the current focus on economic and environmental pillars.

4.5.4 Progression of research findings

The purpose of this pre-COVID-19 study was to investigate both the state of design for student accommodation as well as to consider the issues that an entrepreneurial university or institution would need to consider in order to forge stronger relationships between it and potential partners. This study shows the potential benefit to a university, industry partners and wider society of the development of enduring partnerships based on the delivery of a shared outcome (improving mental health through better

accommodation design) but where each partner will have different desirable outputs (the university outputs would be research; the industry outputs would be a better quality product).

Publication 5 helped to clarify the opportunities open to universities and other institutions to develop partnerships for innovation that cut across all elements of the university (Mission 1: teaching; Mission 2: research and Mission 3: engagement) to partner effectively with industry and government. The findings in Publications 4 and 5 are further developed in Chapter 5 and used to produce an institutional framework to help understand the potential of partnerships for innovation.

The advent of the COVID-19 pandemic, and the impact that isolation has had on mental health across the globe, has underlined the potential value of the proposal.

Chapter 5 Innovation at the university-industry-government nexus. The case of Greater Curtin

This Chapter is a continuation of the enquiry presented in Publications 4 and 5 (see Sections 4.4 and 4.5 and Appendix B.4 and B.5) looking into the use of infrastructure development (Publication 4) and potential opportunities (Publication 5) to develop partnerships for innovation that are based on both the experience of implementing knowledge created and using campus infrastructure to develop new knowledge.

This Chapter continues to address sub-questions 3 and 4.

- Sub-question 3: What factors promote or limit partnership development for a low carbon future?
- Sub-question 4: How can Australian universities become more effective at partnering with Government and industry to drive a low carbon future?

As discussed in section 3.2.5 the data for this Chapter has not been published.

5.1 Background

In 2013 Curtin University presented *Creating the City of Innovation – a vision for Greater Curtin* [99] alongside a campus master plan [100-103]. The vision set out the University's desire to create a "truly globally competitive knowledge centre … and to make a difference to citizens, visitors and the wider community – while ensuring a greater tomorrow for all" [99]. Creating a city of innovation set out a vision to benefit not only the university but also industry for the benefit of Perth and Western Australia [100]. The document was divided into four sections:

- Greater Opportunity which described the economic benefits of the plan;
- Greater Community which discussed the benefits of physical and virtual networks of innovators;
- Greater Learning set out the steps to create a focus on learning and a lifelong framework for the exchange of knowledge; and
- Greater Connections set out how well physically connected the city will be to attract investment but also as a destination.

The concept was to build a city with the sole purpose to innovate, and it would do this through the built environment but also through incidental learning, thinking and new ideas [100]. The documentation foresaw a process that would start in 2013 "even before there are bricks and mortar we will build a city with inspired thought, creativity and knowledge". The projected benefits of Greater Curtin [99-103] are summarised in Table 5.1.

Table 5.1 Projected benefits of Greater Curtin to be realised by 2031

Projected benefits to be realised by 2031			
Greater opportunity	$4.5bn (including $317m exports) annually	762,000m^2 of floorspace	20,000 jobs created
Greater community	20,000 residents in total	8,000 resident students	73,000 daily visitors
Greater learning	44,000 full time equivalent students	6,700 full time equivalent staff	2,300 staff dedicated to research
Greater connections	79% less kilometres driven than Perth average	54% less CO_2 than Perth average	76% less water consumed than Perth average

5.1.1 Greater Curtin - Master Plan

Alongside *Creating the City of innovation* [99] Curtin University also published its three-part master plan [100-103] which set out spatial strategies to support Curtin's vision and the aspirations set by the WA Government Strategic Plan for Perth [104] to guide the university from being an "isolated suburban campus into a major node of activity and a city-wide community asset" [100].

The master plan was developed by a transdisciplinary project group consisting of Curtin Properties, AECOM, Arup, Block Branding, CBRE, Donaldson and Warn, Pracsys and Syrinx Environmental PL. The master plan set out how the 114-hectare campus would be developed over the succeeding 20 years to create a place where "innovation and opportunity co-exist for the taking" [100]. It described the process of forging strong relationships with industry and government to ensure the goals and targets met the demands and changing face of university education and delivery [100].

> *"[T]he master plan seeks to establish a flexible framework that the university and its partners can work with to guide the evolution of an urban centre with*

a strong identity, high levels of vitality, community interaction and opportunities for growth, prosperity and strong partnerships." [100] p10

The Master Plan was conceived around developing a knowledge economy hub in Australia to deliver what Curtin University referred to as four key network strengths [100]. These are set out in Table 5.2.

Table 5.2 Developing network strengths through Greater Curtin master plan

Network	Strength
Education and innovation network	Designed to meet the future needs of students by creating and delivering courses that closely align with industry and community expectations To become the centre of research and innovation in WA blending new practices for entrepreneurship with industry partners
Social and cultural network	A place where art and culture meet technology and innovation. It seeks to become a creative hub for Perth
Urbanisation network	To serve as a living laboratory where research and education are both visible and accessible to all
Business and research network	Greater Curtin will showcase the network benefits to industry and researchers of access to fresh ideas and collaborators

5.1.2 Greater Curtin – student accommodation

The first stage of the Greater Curtin program was the development of a student accommodation project to accommodate 1,500 students on campus. The process to deliver the student accommodation project was to seek expressions of interest (EOI) from suitably qualified companies. These were then filtered and a request for detailed proposals (RFDP) were requested from preferred bidders.

The data collection stage for this Chapter took place after the EOI had been advertised, but before the RFDP had been issued. As the interviews took place during the procurement process no interviewee was able to provide detail on individual bidders. This did not impact upon the verisimilitude of the interviews as they focused on how the accommodation project could or would be used to drive the delivery of teaching and research outcomes as well as the development of partnerships for innovation, rather than an investigation into the procurement process *per se*.

5.2 Summary of findings

Chapter 5 has made the following contribution to the theoretical underpinning of partnership development at the university-industry-government nexus:

- Three themes emerged from the interviews:
    - projects will evolve over time as the potential to deliver teaching and research outcomes is better understood and widely shared;
    - there is a lack of consensus between internal partners as well as external advisors around how to engage, integrate and showcase teaching and research outcomes into the project;
    - provides evidence that the university was not maximising the potential of the project to drive Mission 1: teaching, Mission: 2 research, or Mission 3: engagement to develop partnerships for innovation;
- Proposes an institutional framework to illustrate the potential to progress partnerships, overtime, to deepen the engagement (Mission 3) of university and industry in the delivery of teaching and research outcomes (Missions 1 and 2) through capital infrastructure projects.

5.3 Discussion of findings

The purpose of the interviews was twofold. One was to discuss how the Greater Curtin Stage 1 project had been developed and how different stakeholders within Curtin University were involved. The other element was to discuss emerging constructs from the literature, particularly the two elements that are evident in all bottom-up structures (namely open innovation and user engagement – see Publications 1 and 2 for further discussion) to see if the stakeholders in the project had realised the potential of the project to deliver teaching and research outcomes to enable partnerships for innovation at the university-industry-government nexus.

The findings from the interviews reveal three themes. The first is a general agreement that Greater Curtin, and specifically stage one of Greater Curtin, is the start of the process rather than the end model and the project is likely to evolve with each iteration. It is a process of learning by doing and that, depending on the outcome, the process could change and be adaptable (this is consistent with findings in Publications 1 and 2). The second theme concerns a lack of consensus about how and when to engage

academics, when to value, showcase and develop teaching and research outputs, and when to integrate research strengths into the project. The third theme concerns the creation of partnerships for innovation where there was some evidence of the university collectively not maximising the opportunity of the project to deliver across Mission 1: teaching, Mission 2: research and Mission 3: engagement.

5.3.1 Theme 1 - evolution of the project over time

The interviews reveal a general level of consensus that the student accommodation project represented an important part of the Greater Curtin journey. There was a general level of support amongst all interviewees for the project and what it was seeking to achieve. There was agreement that the project has potential and that it is important to start the process of delivering it.

> *External: One of the issues the university suffered from is that it was such a big project, and the university didn't know where to start from.*

Different views were offered regarding the engagement of the broader university in the project. The Project Control Group, made up from internal and external appointees who co-ordinated the development of the Greater Curtin project, were clear that academics had not been involved in the formulation of the project, but that academic involvement would be valuable.

> *External: We haven't reached out to the university with this project yet, but I can't see any reason why you couldn't incorporate it. The factual position is that we haven't done that at this stage. Could it have been useful? Yes, it could have been.*

> *Professional administrator: Now is a period of no engagement because we are going through a procurement process rather than talking about what it's going to be.*

This disconnect was recognised by the academic administrators who were looking to develop a process to effectively engage all parts of the university with an interest in the project.

Academic administrator: I think there is a gap and it's the formalisation of an internal group that is representative of the different parts of the university in terms of contributing to Greater Curtin.

Academic administrator: Have we had involvement in Greater Curtin innovative precinct? Not really. They are very enthusiastic, but we're not involved formally in the process. I think they probably only have high level concepts.

However, despite the lack of a formal grouping or process it was felt that the academics were having an influence over the development project.

Academic administrator: My understanding as the result is that the RFP … or EOI … required a response to how they would engage the research, the academic community in the development. I think we are influencing it already.

There was also a node in the discussions about the initial ambition of the project. This is consistent with the idea that the university had to start somewhere and learn by doing to understand the potential of the project. The university recognised both that the process was important and whilst ambitious, there was more that could be delivered from future stages.

External: A large part of what I think we are doing is reasonably vanilla.

Academic: He [project lead] *said this project has marginal financial outcomes which restricts how adventurous we can be.*

The interviews revealed a predisposition, particularly amongst the administrators, towards learning by doing, rather than learning from other people's experience. In part this was due to a recognition that the scale of the project was such that the University needed to collectively understand the potential.

External: It's not a straightforward concept. It's a process right? How do you run a process to make sure you have the opportunity to get these sorts of things in?

External: I think the challenge for others is how do we build more of the university into this space? You can't let everyone have a go as you'd get

overwhelmed, but I think now is the time to start to get those ideas to build them into the next phase.

Academic administrator: The question is at what point do you bring the rest of the organisation along so they can start directing their resources appropriately?

5.3.2 Theme 2 – engage, integrate and showcase research and teaching strengths

Whilst the interviews revealed a strong level of support for the Greater Curtin project and an appreciation that the project was the start of a process there was not unity over the best way to showcase, include or use the project to leverage teaching or research outcomes (Mission 1 and Mission 2). The academic interviewees (both research focussed and administrators) argued that more needed to be done to better integrate their work into the project, but also acknowledged that the process was not straightforward.

Academic: A general point is that sometimes institutions don't make use of inventions, the stuff that there is in place in their back yard and sometimes it's for good reasons – you know it's not that they haven't considered it; they have but sometimes it's because they don't value what they have produced, it's kind of you can't just do it because it's from you. If the same thing came out of Harvard, you'd say wow!

Academic: That's certainly an option we could discuss with potential builders about the opportunity to provide opportunity for research and work integrated learning and clearly that is something we would be motivated to do. The only issue about that is that research is inherently risky – you don't do it if you know the answer.

The interviews revealed the development of a conversation about how to showcase teaching and research strengths. This was a conversation more evidenced in the interviews with administrators than academics. Also, the administrative side of the university, responsible for project delivery, whilst supporting the approach of using the project to drive mission 1 and 2 outcomes were more circumspect and were not clear in how to unlock the potential.

Professional administrator: Its obviously not just monetary – is this aspirationally what we want to pay for? Culturally research is part of what we do. If we don't provide opportunities for research, we're not doing what we're supposed to be doing.

Academic administrator: Not just universities it's all organisations. It's a major problem with us to market products we work on because some people seem to have the view that the universities are full of great ideas but if only they would let them go, people would be able to come in grab them and develop then. That's not an accurate representation of what's going on. Where we see new products, we put in money and try to develop it piloting, co-fund all that stuff. But to try to get people to change the way they do things and shift behaviours is difficult and takes time. You really do have to demonstrate really robust and significant benefits for the change.

Professional administrator: You know should we, would we, constrain bidders and say look in addition to kind of all these other criteria you have to demonstrate how you are actually using research that we actually produce. We'd never go that far – you would hope there would be enough value being produced here that they would make use of that.

Professional Administrator: We weren't explicit. We felt that we were unable to be explicit because who does the developer ring up? No one in the university – it's no one's role in the university to take the phone call.

5.3.3 Theme 3 - potential to progress Mission 1, 2 and 3 outcomes

There was also the emergence of a theme, revealed in Publications 4 and 5 (see Section 4.4 and 4.5), revolving around the potential of the project to progress teaching and research strengths in partnership with industry. At its heart is a conversation around how and when research and teaching can be leveraged through Greater Curtin. The traditional project approach would be when the buildings are opened, and this is also evidenced in the interviews, as was a disparate view of how or when to engage with teaching and research.

Professional administrator: research yes. it's also about advancing research capacity because part of what Greater Curtin stage 1 will deliver the

opportunity to house post-grad students and visitors and, you know, visiting fellows, scholars.

Academic administrator: The other part I haven't mentioned has been looking at trying to engage industries or other research organisations that may wish to be tenanted [author emphasis] *within Greater Curtin.*

Professional administrator: There are research and teaching space in there [the Stage 1 project].

External: We're giving another point where thought leadership and creativity can occur. We hope we are going to build space for this. So, we are going to facilitate that to occur through the built form and through that built form we are going to create an environment where people can come together and think about good ideas. We want to create areas that are for start-ups. People will come together for that definitive purpose – arguably doesn't exist on one area of the campus now.

Professional administrator: I don't think we do. We all want these opportunities. But no –one knows how to make it happen. No one has a KPI to say you must make this happen. It's difficult to join the dots. And so, if we can't join the dots how on earth does someone else do it.

The discussion evidenced above sets out responses to the issue of how and when to incorporate research into Stage 1. It reveals a range of views and timing for the engagement of teaching and research outcomes. There are four elements that were evidenced:

- Incorporating research into the project is difficult;
- Research will happen once the buildings have been opened or created;
- Once there is space then business can rent it, or the space can be used to drive partnership development; and
- Once the accommodation is built there will be more students on campus to undertake research.

There was acceptance, though mostly implicit rather than explicit, about the potential for the project and the need for deeper thinking about what it could deliver given time.

> *Professional administrator: We are extremely intelligent, but we don't run a business. What are the blockages? I think it's about the maturity – the business didn't understand the contribution it can make. It thought it was just producing graduates. Well, that's one way of looking at it. But what I am demonstrating with the Master Plan is that if you are developing a knowledge city and there are so many layers that it's not just about developing graduates.*

However, this theme of potential was discussed by particularly academics about how to leverage research to develop partnerships that would deliver future stages of Greater Curtin. This latter theme also included a link to learning from other's experience and as such reflects a development in both the *modus operandi* of the project as well as its ambition.

> *Academic: They are still doing it, but basically, they learnt a lot of lessons in doing that – we could certainly cut something down quite quickly by learning their lessons in building that building.*
>
> *Interviewer: That's research funding their infrastructure?*
>
> *Academic: Yes.*
>
> *Academic: Curtin wants to get external funds – external money is what it is all about. They don't want to be funding research projects within Curtin.*

This does suggest a deeper engagement with the research and teaching community to develop an ambitious approach to the project. Both academics and professional staff understood that to do this would take time – and time is a constraint identified in the conversations suggesting that the university needs to create an environment where academics (and administrators) would be permitted to allocate time to developing projects for Greater Curtin.

Professional administrator: While one of the challenges we have, we often have, our researchers say we want to do this that, but the reality is when the rubber hits the road they fall away because they don't have time commitment

Academic: I'd be more than happy to do stuff, but we'd need to give my group time to do it.

Whilst time to develop projects was an issue, so too was the deeper understanding of the potential of all stages of the project, from project ideation and design to ribbon-cutting, to help deliver partnership development, innovation and delivery of teaching and research excellence.

Interviewer: I'm thinking if the Vice Chancellor gave the Deputy Vice Chancellor Research $85m today and DVCR said 'I'll have you some research outcomes in 2019' she'd go 'you serious?'. But that's what we are doing with Greater Curtin. We're saying jam tomorrow.

External: I know what you are saying! DVCR could probably get a faster rate of return but over 30 years probably our $85m will deliver greater benefits.

Interviewer: It's not either, or is it? We'll give you $85m but as part of the process how do we engage them?

External: I'd answer $50m is you would have to spend anyway. You need new SOBE anyway. $30m for relocating the bus station, putting new road with all the facilities that a new road provides and creating the environment. That's how I might use all your true discretionary expenditure. You'd spend $50m anyway.

Professional administrator: It's the same principle. You've got to try to open your arms. You've got to have partnerships; you've got to have that absolute desire to want to understand. It doesn't mean you have to say yes. You've got to want to understand.

The interviews also revealed an element of distrust between academic and professional staff. This was more strongly vocalised by the professional staff but also evidenced by academics and academic administrators.

Academic: The conversations haven't happened from their end but from my end to them. That's my idea of throwing it out there. I can't do anything more than that. I can only push it.

Academic: I remember saying they have my email, and they know what I want - I've sent it a number of times. I've sent it to Office for Research and Development to start with. The Vice Chancellor was also - I had her on the mailing list as well. Just so you know I got it in front of people's minds.

Professional administrator: As I said what typically happens is – I'll use an example – the non-smoking campaign. How did a particular group that said work our campaign before, during and after it, Sure. But we want $200k to do it. It happens all the time. So why would I do that?

Professional administrator: Look going back to academics and academic freedoms is a problem because right now I would like to shut down every computer in the place that's not being used but academics say it's my right to leave it on and don't turn it off. Really?

Professional administrator: They [non-academic] *said "you're on the road and an emergency vehicle might need to come in". "It's a food truck it can* [swear word] *move". So, you're closing me down? Yes, you're not complying. I said these are all footpaths there are no roads on campus. So, the guys parked on the edge of the footpath on the grass. So, he's done the right thing and moved off the path. It's not a road. Their argument was flawed – because they thought the university operated like a mine site. Again, culture had to change and then once they saw it was OK to have a food truck in the middle of the campus it made sense.*

5.4 Development of an institutional framework to transition top-down structures

Publications 1 and 2 demonstrated that top-down structures were focused on innovation to drive economic growth. Publication 2 also found nothing inherent in the living lab structure that predisposes them alone to the creation of sustainable outcomes. However, it did suggest that the wider engagement with society (though open innovation and user engagement) is a reason why living labs are more predisposed to deliver

innovation in a manner consistent with sustainable development. These findings, alongside the results of the interviews presented in this Chapter and Publications 4 and 5 are summarised in Table 5.3 in the form of an institutional framework.

The institutional framework illustrates the phases of a procurement cycle against which are plotted the potential for a university, with its partners to deliver Mission 1 (teaching), 2 (research) and 3 (engage) outcomes. The institutional framework illustrates the extent of the potential to progressively develop partnerships to enable innovation at the university-industry-government nexus.

The institutional framework is a temporal yet evolutionary adjunct to the Triple Helix model. It is temporal as it represents sequential points in time; it is evolutionary as it facilitates increasing levels of engagement over time; and it is an adjunct as it represents a developing procurement model for partners to use.

Taken together the framework provides a process for top-down, economic focussed partnerships to widen their remit, embrace those elements of the bottom-up approach that appear to be driving the adoption of sustainable innovation and thereby start to develop partnerships to enable low carbon and sustainable innovation at the university-industry-government nexus.

Based on the case study presented in Publication 5 a potential campus infrastructure project was divided into four stages.

- Stage 1 is the ideation phase where a university decides to invest capital (their own or a potential partners) into an infrastructure project;
- Stage 2 is the procurement phase;
- Stage 3 is the construction phase; and
- Stage 4 is occupancy – where the university takes possession of or is given access to the asset.

The institutional framework offers insights into how to develop partnerships for innovation increasingly based on knowledge as well as learning by doing and how, over time, to deliver Mission 1, 2 and 3 outcomes in all aspects of infrastructure development.

The institutional framework demonstrates a progression in the incorporation of partnerships (Mission 3) to drive the delivery of teaching (Mission 1) and research (Mission 2) outcomes in an infrastructure project in a university setting over time.

- **Early phase** represents the traditional approach whereby a project is conceived, and university administration staff are tasked with project delivery. There is a procurement stage the result of which is the award of a contract to a company who then builds the facility. University academics might be involved in the process at project ideation (if it is an academic related project) and then will have access to the building on completion of construction. The result is that research and teaching can only happen once the ribbon is cut, and this is represented in the coloured box in Table 5.3. The early phase has similarities with a Mode 1 approach to knowledge production (discipline based – but in this case demarcated within the institution rather than based on academic discipline; not applied). This method is loosely referred to in the interviews as "jam tomorrow" procurement where delivery of teaching and research outcomes only happen after construction.

Table 5.3 Proposed institutional framework for partnership development at the UIG nexus to deliver teaching and research outcomes

<table>
<tr><th rowspan="2">institutional progression</th><th colspan="4">Potential partners</th></tr>
<tr><th>Stage 1: ideation & creation</th><th>Stage 2: Procurement</th><th>Stage 3: Construction</th><th>Stage 4: Occupation</th></tr>
<tr><td rowspan="2">Early phase Mode 1</td><td>U – administration</td><td>U – administration
Industry</td><td>U – administration
Industry</td><td>U – academic</td></tr>
<tr><td colspan="3"></td><td>Delivery of TRO</td></tr>
<tr><td rowspan="2">Middle phase Mode 2</td><td>U – administration
U – academic</td><td>U – administration
Industry</td><td>U – administration U – academic
Industry</td><td>U – academic
Industry</td></tr>
<tr><td></td><td>Potential for TRO</td><td colspan="2">Delivery of TRO</td></tr>
<tr><td rowspan="2">Mature phase Mode 3</td><td>U – administration
U – academic
Industry
Users</td><td>U – administration
U – academic
Industry</td><td>U – administration U – academic
Industry</td><td>U – academic
Industry</td></tr>
<tr><td>Potential for TRO</td><td colspan="3">Delivery of TRO</td></tr>
</table>

Key: U = University; TRO = Teaching and research outcomes (Mission 1 and 2)

- **Middle phase** represents progression on the Early phase and is evidenced by the findings set out in Section 5.3.2. In the Middle phase academics are more closely involved in the process of project development and delivery (and this involvement would be even if the proposed project was not academic (for example delivery of student accommodation). The Middle phase provides academics with the opportunity to partner with potential bidders either through provision of existing research and knowledge or through the creation of new knowledge or teaching opportunities which would create value for the university and its partner. The middle phase has a closer affinity with Mode 2 knowledge production (transdisciplinary, applied with knowledge shared between partners).

  In the Middle phase the potential for teaching and research deliverables could accrue potentially during the procurement phase (for example through research outputs such as this thesis) but certainly during the construction and occupation phases. The Middle phase provides the university with greater value and a clearer focus on Mission 1 and Mission 2. However, as a move away from the traditional approach represented in the Early phase, it would also create its own risk profile which would need to be managed.

- **Mature phase** represents further progression still. It too is evidenced in the interviews (and Publication 5) but less explicitly than the Middle phase. It is, however, theoretically robust. The Mature phase presents a more nuanced approach to project development and delivery and has a close relationship to Mode 3 knowledge production (transdisciplinary, applied and shared with society).

> *Professional administrator: We are extremely intelligent, but we don't run a business. What are the blockages? I think it's about the maturity – the business didn't understand the contribution it can make.*

The Mature Phase is significant because it is more focused on open innovation and the co-creation of projects between businesses and the university through the application of knowledge and experience from this and other projects throughout the project lifecycle. As such the potential to derive teaching and research outcomes are evidenced from Stage 1 (ideation) through to Stage 4 (occupation). Such learnings and knowledge will then be carried forward to the next iteration or project,

which will benefit from knowledge created as well as learning by doing. As a progression from Middle phase (above) this iteration would also create its own risk profile which would also need to be managed. As illustrated, it could be developed further through the addition of users into the partnerships.

5.5 Discussion of proposed institutional framework

The focus of the framework is institutional as this research suggests that it is the institution, rather than partnership structures themselves that are preventing top-down structures from innovating in a manner consistent with sustainable development (see Section 4.4.4). The framework also associated the modes of knowledge production (see Table 2.2 for detail) to the phases of institutional development. This is an association rather than causal link, but it is a useful addition to the model as it helps to draw attention outside of the partnership structure to the changing way knowledge is produced and applied.

The framework also introduced into the institutional setting those factors (transdisciplinary teams and in the Mature phase users to co-create innovation) that may predispose living labs to be more focused on low carbon transition enabled by innovation at the university-industry-government nexus.

The framework reveals two further significant insights: one is that as the framework matures the ability to derive teaching and research value for the university, society and partners comes earlier in the project life cycle; potentially with each iteration.

The other is that each iteration would benefit from knowledge created either by the university or its partners. This would explicitly be brought to the programs ensuring that lessons from previous experiences are learnt and mistakes avoided. As a risk management regime this too will add value to the university. Risk would not be removed but management would be more knowledge based.

This framework is the result of research into the development of Greater Curtin Stage 1 and is therefore focussed on universities, but it could be developed as an *aide memoire* for industry and government. It is represented here as a linear process, but it too is likely to be a rotating helix.

5.6 Further research

The benefit of the institutional framework is that it is scalable and transfers knowledge forward so that future partnership development will not need to be focussed on learning by doing within the project but rather learning from what other people (and potentially other partners) have already done. The framework needs to be tested to be validated, but it does offer an evidence-based model for partnership development.

Further work would be useful to understand more deeply the motivators for and influences on project ideation as it is at this stage that the potential to drive economic, social and environmental outcomes are set. Publications 1 and 2 demonstrated that the majority of literature reviewed is focused on the economic benefits of partnerships for innovation. Publication 2 showed that there is a thin stream of work, derived in a bottom-up process, looking into economic, social and environmental outcomes from partnerships for innovation. Publication 3 also proposed that the use of the sustainable development goals be used to drive research. Further research on the process to agree the scope of potential projects would be informative. This issue is developed in Chapter 6.

Chapter 6 Synthesis

This Chapter brings together the findings from the five publications, as well as Chapter 5 and applies the evidenced findings to the research questions. Section 6.1 presents a discussion of the research progression addressing each of the sub-questions and Section 6.2 provides a summary of the findings evidenced in the research.

6.1 Research progression addressing the sub-questions

The progression of the research through the publications and throughout this thesis is set out in Table 6.1. It demonstrates the contribution of each of the publications, as well as previously unpublished work presented in Chapter 5 to answering the research questions.

Table 6.1 Research progression through the thesis

Publication	Primary research question	Summary of findings	Research progression through thesis
Publication 1 A systematic literature review of partnership development at the university-industry-government nexus	Which partnership models at the UIG nexus have been successful to deliver innovation?	Development of an evolutionary approach to the development of partnerships at the UIG nexus	Findings developed in Chapter 7
		Living labs are the partnership structure that address economic social and environmental issues at the same time	Finding further explored in Publication 2
		Development of hypothesis linking evolution of partnerships for innovation, globalisation of economy, society and environment and changes in modes of knowledge production	Findings developed in Chapter 7
Publication 2 Business models for sustainability in living labs	Which partnership models at the UIG nexus have been successful to deliver low carbon and/or sustainable innovation?	Business cases differed due to the impact of three factors: why created; response to internal opportunities or external pressures	Findings developed in Section 6.2
		Demonstrated Triple helix can be implemented locally; path dependency helps to understand decision making; value of being part of a consortium to learn from experience and by doing	Issues further examined in Publication 3

Publication	Primary research question	Summary of findings	Research progression through thesis
Publication 3 If living labs are the answer what is the problem?	What factors promote or limit partnership development for a low carbon future?	Australian universities and industry are weak, when compared to OECD counterparts at partnering for innovation;	Ideas developed in Publications 4, 5 and Chapter 5
		Universities do not make the most of their campuses to drive partnership development	See Publication 4
		Rate of external change makes partnership development complex and uncertain	See Chapter 7
		Proposed that SDGs should be used as the framework to drive partnerships at the UIG nexus	See Chapter 7
		Foray into process of organisational decision making	See Chapter 7
Publication 4 A study of Australian universities' collective response to climate science	How can Australian universities become more effective at partnering with Government and industry to drive a low carbon future?	Universities not developing experience implementing knowledge or of developing partnerships	See Chapter 5
		Evidence-based innovation could drive partnerships	See Publication 5
Publication 5: Happy homes – the relationship between homes and mental wellbeing.	How can Australian universities become more effective at partnering with Government and industry to drive a low carbon future?	Example of types of issues that an entrepreneurial university could tackle through partnership using infrastructure development	See Chapter 5

Publication	Primary research question	Summary of findings	Research progression through thesis
Chapter 5: Innovation at the university-industry-government nexus. The case of Greater Curtin	How can Australian universities become more effective at partnering with Government and industry to drive a low carbon future?	Development of three themes: projects evolve; lack of consensus as to how to integrate teaching and research outcomes; and not maximising potential to integrate Mode I,2 and 3 into partnerships for innovation	Proposes an institutional framework for partnerships development, which is used in Chapter 7

6.1.1 What partnership models at the university-industry-government nexus have been successful to deliver innovation?

This research has produced two findings to assist with answering this question. Firstly Publication 1 revealed an evolution in the development of partnerships for innovation at the university-industry-government nexus where partnership structures are becoming increasingly complex. This finding builds on, rather than replaces, the top-down/bottom-up presentation of the creation partnerships for innovation current in the literature.

The three stages, as revealed in Publication 1, are:

- Development of on-campus structures. Such structures include technology transfer officers or offices, space for business incubation, access to library services and information and potentially access to capital;
- Development of campus-adjacent structures. This stage is represented by the development of science and technology parks. These are developed proximate to a university, or cluster of universities and are designed to help industry work with universities to commercialise knowledge; and
- Development of living labs (and derivatives). These are partnership structures based on user engagement and open innovation. They are footloose and can be found in a variety of locations, including on-campus and campus-adjacent.

Secondly, Publication 1 also revealed that the partnerships were primarily focussed on delivering economic benefits from the commercialisation of knowledge with over 100 of the 132 articles reviewed being grounded in theories of economic development (see Appendix B.1 for full details).

Publication 1 also showed, in concert with other work (for example see [14]), the relative paucity of research looking at partnerships for innovation delivering economic, social and environmental outcomes at the same time. Publication 1 did however reveal that the only partnership structure that has been used to deliver economic, social and environmental outcomes at the same time is the living lab and its derivatives. This finding is summarised in Table 6.2 and is interesting because partnerships at the university-

industry-government nexus include the government, which is responsible for policy on sustainable development, and has agreed to the adoption of the sustainable development goals, and universities which provide some of the research that government's use to develop policy (for example climate science – this is discussed further in Publication 4).

Table 6.2 Partnership structures delivering innovation with economic, social and environmental outcomes

<table>
<tr><th>Evolution of Partnerships for Innovation</th><th colspan="3">Effectiveness of partnerships to deliver innovation</th></tr>
<tr><td>On campus</td><td rowspan="3">Economy</td><td></td><td></td></tr>
<tr><td>Campus adjacent</td><td rowspan="2">Society</td><td></td></tr>
<tr><td>Living labs</td><td>Environment</td></tr>
</table>

Publication 1 also revealed that there are a series of factors, outside the control of the partnership that are influencing the evolution of partnership development and potentially the focus of the partnerships.

The deepening of the knowledge economy and the increasingly ubiquitous access to the internet have accelerated the evolution in partnerships for innovation. Further, moves in Europe towards Responsible Research and Innovation [105] and the engagement of wider society in the development of research and innovation programs suggests a further pressure on the partnerships to evolve. Publication 1 refers to this move as the globalisation of society which is taking place alongside the globalisation of the economy and environment.

These findings led to the development in Publication 1 of a hypothesis (see Table 6.3) that proposed a link between the evolution of partnerships for innovation at the university-industry-government nexus, and the external influence of the globalisation of the economy, society and environment alongside the changing modes of knowledge production. This hypothesis is developed further in Table 6.3 and the development of a metastructure to enable innovation at the university-industry-government nexus is revealed in Chapter 7.

Table 6.3 Hypothesis of relationship between partnerships, globalisation and modes of knowledge production

Evolution of Partnerships for Innovation	**Effectiveness of partnerships to deliver innovation**			**Mode of knowledge production**
On campus	Economy			Modes 1 and 2
Campus adjacent		Society		Modes 2 and 3
Living labs			Environment	Mode 3

6.1.2 What partnership models at the UIG nexus have been successful to deliver low carbon and/or sustainable innovation?

As discussed, Publication 1 confirmed results elsewhere (for example see [14]) demonstrating a relative lack of research looking into the use of partnerships for innovation to deliver economic, social and environmental outcomes at the same time. Publication 1, as shown in Table 6.2, did reveal that the only structure used to produce innovation that was consistent with sustainable development outcomes was the living lab and its derivatives.

To answer this sub-question Publication 2 investigated the development of the business cases for four sustainability labs (SusLabs) that were part of the SusLabNWE consortium. It shows that the living lab approach is effective for creating partnerships for innovation to deliver sustainable outcomes, that the Triple Helix model can be applied in a local context and that members value being part of the consortium to share knowledge and reduce the burden of learning by doing.

Publication 2 shows that the factors affecting the development of the business cases were driven by the different objectives of each SusLab and that this reflected how each SusLab was originally created. It showed that business cases evolve according to internal and external pressures and opportunities.

Importantly, Publication 2 also found nothing inherent in the living lab structure that predisposes them alone to the creation of sustainable outcomes. However, it does suggest that the wider engagement with society (which in living labs focused on open innovation and user engagement (see Publication 1)) is a reason why living labs, rather than the other structures researched, are more predisposed to deliver

innovation in a manner consistent with sustainable development. This issue is investigated further in Chapter 5.

Other research in this thesis contributed to the understanding of how other structures could be used to drive sustainable innovation. Publication 4 demonstrated that universities were not capturing the potential benefit of their research into climate science to develop partnerships for innovation. Publication 5, and Chapter 5, presented work that demonstrates the importance of the institutional setting to create partnerships for innovation. Publication 3 proposed the use of the sustainable development goals to drive the development of research and innovation at the university-industry-government nexus, as the factor limiting the creation of sustainable innovation does not appear to be structural, but rather institutional.

6.1.3 What factors promote or limit partnership development for a low carbon future?

This body of research has found no factors that predispose one type of partnership structure to low carbon, or sustainable innovation. It is posited above that the inclusion of users and open innovation in living labs is a factor in encouraging the development of partnerships for innovation that is more consistent with the objectives of sustainable development. As discussed in Section 4.4.4 and above, there is nothing structural to prevent the top-down structures from being used to deliver low carbon, and sustainable transition through innovation at the university-industry-government nexus.

Publication 3 found that Australian universities and industry, when compared to their peers in the OECD, were weak at collaboration for innovation, even though industry funds public research in Australia at a level higher than their OECD counterparts [48] and that 90% of Australian universities' research outputs are world class or better [51].

To understand further the reasons for poor performance in partnering for innovation Publication 4 investigated Australian universities adoption of climate research and the use of campus redevelopment to drive low carbon transition. It showed that in 2015 7% of universities have adopted a science-based carbon reduction target. Further it demonstrated that 20% of Australian universities were using their campuses to drive innovation in general, with one university committed to doing so in its long-term strategy.

Publication 4 presented an interesting question. Universities were committed to investing $1.5bn capital into campus development in 2016, of this approximately $500m was explicitly tied to the delivery of teaching and research outcomes. The research did not reveal how the remaining $1bn would be used. But it suggests that universities were not using their resources effectively to drive Mission 1 and 2 or partnerships for innovation (Mission 3).

Publication 3 also attempted to explore, through a transdisciplinary methodology, the process of decision making (rather than the factors that affect decision making that were raised in Publication 1). This was ultimately unsuccessful although logically sound and worthy of further investigation (see Chapter 8 for recommendation).

6.1.4 How can Australian universities become more effective at partnering with government and industry to drive a low carbon future?

Having resolved that there is not one form of partnership structure that is inherently better, or more sustainable than others the research turned to focus on the potential to use campus redevelopment to develop partnerships for innovation.

To do this Publication 5 and Chapter 5 used Curtin University's proposed development of a 1,500-bed student accommodation project to understand how a university could drive teaching and research outcomes, partnerships and innovation through such a project.

Publication 5 scoped the issue of mental health and housing and found that at the non-intervention (i.e. those who are mentally healthy) end of the mental health continuum there is little in the literature reviewed to help an individual use their accommodation to support good mental health. Much of the advice (pre-COVID-19) surrounded the importance of leaving your accommodation to get better, as isolation was likely to be inconsistent with furthering positive mental health. The paper found several issues on which a student accommodation project could be used to both research the links between accommodation and mental health and partner with industry to undertake translational research to test solutions.

The practitioner interviews, described in Chapter 5, led to the creation of an institutional framework to illustrate how universities could progressively engage with

industry over the life cycle of an infrastructure project (see Table 5.3). The significance of this institutional framework is that it offers universities, industry and government an understanding of the potential to use infrastructure projects to drive innovation in partnership. It shows how each partner would achieve tailored benefits through partnering in the project.

Using student accommodation as an example, universities would benefit through research outcomes; business would benefit by being able to offer a better product and government (as the representative of broader societal interest) would benefit through the commercialisation of research outcomes as well as student accommodation designed to support positive mental health.

6.2 Summary of evidenced research contribution to each sub-question

The theoretical contribution of the five publications (Appendix B.1 to B.5) and Chapter 5 is detailed below.

The overall research question was: how can universities, industry and government together drive low carbon innovation and transition?

The findings presented so far in this thesis evidence that:

- There is an institutional, rather than structural, weakness in developing partnerships for innovation that contribute towards the delivery of sustainable development;
- The Triple Helix model can be used to facilitate the delivery of sustainable development; and
- The institutional response could be to place the sustainable development goals at the heart of the triple helix, around which each helix revolves.

6.2.1 Contribution: Sub-question 1

Sub-question 1: Which partnership models at the university-industry-government nexus have been successful in delivering innovation?

The findings presented in this thesis addressing sub-question 1 evidence that:

- The Triple Helix model is widely cited in the literature and has successfully been applied locally; other models (for example the Quadruple and Quintuple Helix) have unresolved weaknesses;
- The partnership structures are evolving over time and due to external influences (such as the globalisation of the economy, society and environment) becoming increasingly complex; and
- The predominant focus in the partnerships reviewed is on the delivery of economic benefits to society with only a small sub-set seeking to promote economic, social and environmental benefits. There is no evidence of structural reasons for this (for example the Triple Helix model is used to deliver sustainable innovation through living labs).

6.2.2 Contribution: Sub-question 2

Sub-question 2: Which partnership models at the university-industry-government nexus have been successful in delivering low carbon and/or sustainable innovation?

The findings presented in this thesis addressing sub-question 2 evidence that:

- The Triple Helix model can be applied locally and to the development of innovation to deliver economic, social and environmental outcomes;
- There is nothing inherent in their structure that suggests only living labs are appropriate to the delivery of sustainable innovation; and
- Business cases evolve due to internal and external opportunities and pressures.

6.2.3 Contribution: Sub-question 3

Sub-question 3: What factors promote or limit partnership development for a low carbon future?

The findings presented in this thesis addressing sub-question 3 are that:

- No factors were found that predisposed one type of partnership structure to low carbon, or sustainable innovation;
- The inclusion of users and open innovation in living labs may make it more amenable to the delivery of innovation consistent with the objectives of sustainable development;

- Australian universities and industry, when compared to their OECD counterparts, are poor at collaborating for innovation; and
- There is evidence that universities are not maximising the potential of their research findings or capital investments to develop partnerships for innovation.

6.2.4 Contribution: Sub-question 4

Sub-question 4: How can Australian universities become more effective at partnering with Government and industry to drive a low carbon future?

The findings presented in this thesis addressing sub-question 4 are that:

- The potential to use campus redevelopment to progress all 3 university missions (teach, research and engage) is currently underutilised;
- All three missions can be developed using the institutional framework developed as part of this thesis; and
- The institutional framework can be used to further low carbon and sustainable innovation.

Chapter 7 A new metastructure to enable innovation at the university-industry-government nexus

There has been discussion at length in this thesis concerning the evolution of partnerships for innovation and the development of a hypothesis to link this evolution to the globalisation of the economy, society and environment. There has also been discussion about the top-down/bottom-up focus in the existing literature to explain the creation of partnerships for innovation and how this interacts with the evolution of partnerships for innovation. This Chapter draws these discussions together to develop a metastructure to enable innovation at the university-industry-government nexus.

Section 7.1 to 7.3 presents a theoretical application of the research findings evidenced in Chapter 6 to the existing theoretical models. Section 7.4 discusses the implication of the theoretical contribution and Section 7.5 discusses its limitations. In response Section 7.6 proposes the development of a metastructure to enable innovation at the university-industry-government nexus which is discussed in detail in Section 7.7. Section 7.8 summarises the proposal, with Section 7.9 integrating the metastructure and the institutional framework. Section 7.10 discusses limitations of the proposed metastructure. Finally, Section 7.11 proposes a future research agenda.

7.1 Realising the potential of a Triple Helix partnership

This section firstly applies the research findings evidenced in Chapter 6 to the theoretical partnership models for innovation at the university-industry-government nexus which provides a substantive contribution to the overarching research question: how can universities, industry and government together drive low carbon innovation and transition?

Publication 1, along with others, demonstrated that within the literature there is a dearth of articles concerning how to develop partnership structures to further social, economic and environmental benefits to the partners and to society more widely. As discussed extensively the only structure that has focussed on the delivery of sustainable innovation (i.e., innovation that furthers societal interests of economic development, social cohesion and environmental rectitude) is the living lab structure.

As also discussed this thesis found no evidence of structural reasons preventing top-down structures from being used to develop partnerships to innovate in a manner seeking to deliver economic, social and environmental benefits at the same time. This suggests that the reasons for the current focus being on economic benefits are institutional rather than structural.

7.2 Summary of current models proposed to drive low carbon innovation

The existing literature proposes two models to develop partnerships for innovation that help to deliver sustainable innovation through the addition of a fourth and fifth helix to the Triple Helix model (see Section 2.2 and Appendix A.9 and A.10).

Both proposals have limited merit. The addition of a fourth helix – proposed to represent the interests of society is interesting as it raises the issue of how the interests of the global citizen (rather than the locally impacted citizenry) are represented. This key question is, however, currently left unanswered by the addition of a fourth (quadruple) helix (see Appendix A.9 for an extended discussion).

To represent the interests (or otherwise) of the environment a fifth conceptual helix is added to create the Quintuple Helix. The role of the fifth helix is to represent both planetary boundaries and to drive a more environmentally enlightened decision-making process. As discussed, the Quintuple Helix is conceptually weak and does not offer an effective explanation as to how the additional fifth helix would work in practice to drive at the partnership level, innovation that benefits the global citizen as well as the local partners. The conceptual problems with the proposed fifth helix are discussed in more detail in Section 2.2.3. and Appendix A.10. The unresolved problem of the Quintuple Helix is that there remains a scalable disconnect between the local delivery of planetary boundaries but without a mechanism to understand what the boundaries are. This is a restatement of the problem of the un-managed commons [91] that under the Quintuple Helix model remains unanswered.

7.3 How can universities, industry and government together drive low carbon transition through innovation?

The evidence presented in this research is that there are a minority of partnership structures that are delivering sustainable innovation. The evidence presented shows

that top-down structures are not delivering innovation that is consistent with a low carbon, or sustainable future. This research has also shown that there is nothing inherent in top-down approaches that precludes the adoption of sustainable innovation (see Section 4.4.4).

This research has shown that there is an institutional rather than structural issue that lies at the heart of the challenge to contribute to low carbon and sustainable transition through innovation at the university-industry-government nexus.

Therefore, the challenge for this research is to find a way to create an institutional response so that all partnerships developed (top-down or bottom-up) will contribute to a low carbon and sustainable transition.

One proposal, developed from Publication 3, is to use the sustainable development goals (see Appendix A.4.1) as the guiding principles under which to create the institutional response. It is a surprisingly simple conclusion, which would need further applied research, but applying the sustainable development goals to the high-level triple helix framework would result, in theory at least, in all partnerships being informed by, and contributing to, the delivery of the sustainable development goals.

The advantage of adopting this approach to the broader Triple Helix partnership is that the partners are extremely well informed. Governments unanimously agreed to the adoption of the sustainable development goals and are responsible for policy; universities research and teach the goals and business has a direct business interest in operating sustainably. Making sure innovation happens in a manner that is appropriate for the 21st century and addresses the transdisciplinary issues that beset society would be a significant step towards a sustainable society.

7.4 Implications of findings

The proposed modification to the Triple Helix framework model to incorporate the sustainable development goals as a core, unifying proposal around which the triple helices revolve is new to the literature. Including the SDGs as a unifying principle around which to develop low carbon or sustainable innovation ensures that all partners understand what they are seeking to deliver for society in the widest sense, as well as for themselves (in the narrowest sense).

This innovation to the model leaves in place the triadic imperative discussed by Etzkowitz, and borrowed from Simmel, Marx and Webber. It also resolves the shortcomings of the Quadruple and Quintuple Helix models (see Sections 2.2 and 2.2.3 and Appendix A.9 and A.10).

The model now addresses the un-managed commons by demanding that partnerships for innovation focus on achieving global priorities by ensuring that local decisions are consistent with those global priorities. However, it is not didactic as it leaves to each local partnership the imperative of how to innovate in a manner that is consistent with and contributes to the delivery of the sustainable development goals. It is not telling each partnership what to do, but rather it is letting each partnership decide how best to contribute towards the delivery of sustainable development as well as their local, national or international partnership.

The approach future proofs the partnerships by utilising an international agreement that was agreed unanimously by all member nations of the United Nations.

The approach helps to increase the relevance of the sustainable development goals by putting them at the centre of policy development and partnership delivery. This creates a uniform basis for innovation that is as relevant to industrial democracies and autocracies and less developed economies and societies.

Some partnerships (a limited number) are already delivering economic and social outcomes from innovation; a smaller number are still innovating to produce economic, social and environmental outcomes at the same time. This proposal would not adversely affect these partnerships, but any unintended consequences would need to be further understood.

Finally, implementing the sustainable development goals as the centre piece to which the partners revolve around also reflects the move toward open science and reflects the move to mode 3 knowledge production where knowledge is produced in a transdisciplinary plane and this transdisciplinary approach will be continued into the delivery of the innovation. Implementation can prepare partnerships for a progression to transdisciplinary innovation, a progression that is already evidenced in the literature. This issue is discussed further in Section 7.6.

7.5 Limitation of proposal

The proposed addition (see Section 7.3) of the sustainable development goals to become the core of the Triple Helix model is new to the literature. It is a simple yet potentially powerful contribution to the theoretical literature to help create partnerships to develop low carbon and sustainable innovation.

However, whilst an important theoretical contribution it does little to draw together the various theoretical appendages that contribute to the development of partnerships for innovation at the university-industry-government nexus. The proposed metastructure, developed in Section 7.6 helps in this endeavour by demonstrating the interrelationship between the internal and external drivers of partnerships for innovation and within this metastructure the theories and models discussed in this thesis regarding partnership development would sit. The metastructure also helps to understand why top-down partnerships have not been used to drive sustainable innovation and yet living labs have.

7.6 Development of a metastructure to enable innovation at the university-industry-government nexus

As discussed, the development of the actual partnerships heretofore has been seen to be either top-down or bottom-up initiatives and the location of the partnership has not been seen to be important. This research is proposing a new metastructure which focusses on where the partnership is happening and the factors that are influencing partnership development.

Top-down initiatives are management led and reflect the intentions of the broader partnership framework. Top-down initiatives include the creation of technology transfer teams or officers, access for business to library resources, or the creation of incubator space as well as the creation of forms of venture capital funding [39].

In the metastructure this stream of development, as identified in Publication 1 is largely within the physical confines of the university campus and is referred to as on-campus development. Work presented in Publications 4, 5 and Chapter 5 would sit within Stream 1.

The next step in the evolution is Stream 2 which is the creation of campus adjacent structures. These are widely referred to in the literature and consist of science and technology parks, innovation parks and derivatives. The creation of stream 2 structures is also seen in the literature (Publication 1) as being a largely top-down response within the Triple Helix structure.

However, the literature also describes a set of responses that are bottom-up. They come from within the partnership, but they are not management led. This bottom-up development of intermediaries for innovation encompasses a more diverse set of structures, which in the literature is labelled as living labs (and derivatives) and represents a third stream of development of partnerships for innovation.

Stream 3 may then be further divided into two; where Stream 3a represents living labs that are focused on innovation to deliver economic and social innovation and Stream 3b (a smaller subset) that focusses on innovation that delivers economic, social and environmental outcomes at the same time. A summary of the development of the three broad streams is presented in Table 7.1.

Table 7.1 Streams of partnership development in the metastructure

Stream	**Examples**
Stream 1: On campus structures	Access to libraries, business incubators; technology transfer offices
Stream 2: Campus adjacent	Science and Technology Parks
Stream 3: Living labs	A rapidly changing partnership structure; possibly unique to each partnership but focused on user engagement and open innovation

7.7 Integrating exogenous factors and modes of knowledge production into the metastructure

One important aspect of the proposed metastructure is that it links factors exogenous to the partnerships to the evolution of the partnerships. For example, the interesting point to note about Stream 3 it has arisen at the same time as the development of access to the internet and the changes in knowledge production. The literature debates in detail the changing of modes of knowledge production (see for example [20, 21]) but a contribution of this thesis is to link the evolution of partnerships

for innovation to these exogenous factors as well as the development of modes of knowledge production. This finding is developed from the hypothesis presented in Publication 1 and is set out in Table 7.2.

Table 7.2 Development of the metastructure to enable innovation at the university-industry-government nexus

External stimuli	**Manifestation in society**	**Mode of knowledge production**	**Extant model in the literature**	**Partnership stream**	**Spheres of interest**
Globalisation of the economy	Deepening of the knowledge economy	Mode 1 and Mode 2	Triple Helix Model	Stream 1 Stream 2	Economic
Globalisation of society	Democratisation of knowledge	Mode 2 and Mode 3	Quadruple Helix Model	Stream 3a	Economic Social
Globalisation of the environment	Sustainable development goals (etc)	Mode 3	Quintuple Helix Model	Stream 3b	Economic Social Environmental

This three-stream metastructure is an evolutionary addition to the top down/bottom-up model. Importantly it does not replace the top-down/bottom-up emphasis, but rather uses it to demonstrate how the partnerships are evolving (i.e., what factors are driving the development of the partnership structures).

The contribution of the three-stream metastructure is to illustrate developmental progression (see Table 7.3) in the creation and deployment of partnerships for innovation which happen reflexively as opportunities arise (i.e., in response to an opportunity or threat) rather than in the current didactic orientation presented in the literature.

As discussed in Chapter 1 and 2, in detail in Appendix A and Publication 1, and presented in Table 7.2, stream 1 and 2 partnerships for innovation are predominantly driven by the delivery of economic growth. The metastructure suggests this is because Stream 1 and 2 structures were created before the globalisation of society and the democratisation of knowledge [16] and in a period when modes of knowledge production were transitioning from Mode 1 to Mode 2.

Stream 3 structures were created during or after this period and their structures therefore reflect a deeper engagement with users and an emphasis on open innovation. This association is presented in Table 7.3. The fact that Stream 1 and 2 structures remain focused on economic growth may be linked to path dependence theory (see Publication 2) and Stream 1 and 2 partnerships therefore need a process to help them move to structures that more closely reflect the external environment within which they sit. This is the institutional framework presented in Chapter 5.

Table 7.3 Three stream metastructure of partnership development

Stream	**Orientation**	**Date**	**Location**	**Innovation outcome**
Stream 1	Top down	1960 and onwards	On campus structures	Economic
Stream 2	Top down	1960s (USA) 1980s (UK) 1990s (EU)	Campus adjacent structures	Economic Social (limited)
Stream 3a	Bottom-up	2000s	Living labs (and derivatives)	Economic Social
Stream 3b	Bottom- up	2000s	Living labs (e.g., SusLabs)	Economic Social Environmental

The literature shows an increasing interest in partnerships for innovation (Publication 1) and particularly the bottom-up approaches (see also [14]). This level of interest has increased in concert with the increasingly ubiquitous access to the internet and coincides with the development of open science and responsible research and innovation initially launched in Europe [106] but also America and Australia [105]. This research has not found a causal link, but Publications 1 and 2 do suggest a connection worthy of further research (see Table 7.4 and further discussion in Chapter 8).

Table 7.4 Hypothesis of partnership response to external stimuli

External stimuli	Innovation model	Stream	Innovation response	Partnership response
Deepening of the knowledge economy	Triple Helix	Stream 1 & 2	Entrepreneurial university [8]	Incubators Venture capital Science and technology parks
Democratisation of knowledge	Quadruple Helix	Stream 2 & 3a	Service dominant logic [107] Open innovation [17] User innovation [14] User centred design [108] Social innovation [109]	Living lab Urban living labs
Sustainable Development Goals	Quintuple Helix	Stream 3b	Frugal innovation [110]	Sus Lab Smart Cities

7.7.1 Stream 1: Innovation Partnerships – on campus developments

Publication 1 presented on-campus structures as largely concerning the creation of new structures. Publications 3, 4, 5 and Chapter 5 have led to a re-evaluation and consequently Stream 1 therefore consists of two parts. Part 1 is the creation of new organisational structures and infrastructure to create partnerships for innovation (as described in Publication 1). Part 2 focusses on institutional processes to enable using the existing infrastructure in a different manner (as described in Publications 3, 4, 5 and Chapter 5). This is presented in Table 7.5.

The literature reviewed for Publication 1 revealed that partnership structures were often binomial (that is an arrangement between a university and industry, but without government's active involvement). This created a theoretical quandary in the literature as it suggests a binomial relationship is not consistent with the Triple Helix relationship. This issue, amongst others, made the Triple Helix too nebulous to be useful in real partnerships on the ground.

For the metastructure this is not an issue as the focus is on partnership creation between different institutions to commercialise the knowledge to create innovation.

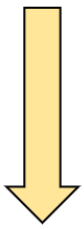
These partnerships do not require the active involvement of government, and as such the metastructure is a relevant contribution to binomial or trinomial partnerships.

Table 7.5 Stream 1 – on campus structures

Stream 1		**Examples**	**Author**
Part 1	Creation of **new** structures	Technology transfer offices Academic liaison officer Business access to library services Business incubation	[80] [81] [79] [82]
Part 2	Either using **existing** infrastructure in a different manner; or rethinking processes	Opening up the campus to new usages Institutionalisation Campus renewal through planning Infrastructure redevelopment	[111] [112] [113] Chapt 5

For example, the university-industry partnerships structures, as put forward by Universities Australia in Table 7.66, make sense in the metastructure. These forms of binomial partnership can vary from the formal to the informal [51] and may occur in stream 1, 2 or 3 partnership structures. This issue is discussed further in Chapter 8.

Table 7.6 Forms of university-industry partnership

University/business relationship	**Type of relationship**
Contract Co-location Expert in residence Collaborative Student placement Innovation networks Industry advisory groups	Formal  Informal

7.7.2 Stream 2: Development of campus adjacent structures

Stream 2 is the creation of off-campus, or campus adjacent structures to further the partnership between universities, industry and government. The impetus for the creation of these off-site structures appears to be university, or government driven. They are geographically proximate and tend to focus on the research strengths of the university.

The effectiveness of such structures in successfully commercialising knowledge created in universities is much debated. There is evidence, presented in Publication 1, of the value park users attach to being part of a community of interest. The informal value park users place on being part of a community is a finding also reflected in Publication 2.

7.7.3 Stream 3: Living labs and derivatives

Living labs are widely discussed in the literature, Publication 1 and Publication 2. As acknowledged in Publication 1 living labs are evolving at such a rate that they are difficult to define, or to develop best practice models. Stream 3 is subdivided into two separate (but co-existing) typologies that reflect the nature of the literature revealed in Publication 1.

Stream 3a focuses on living labs and urban living labs. These are user focussed and co-create innovation. They typically embrace the views of society but do not necessarily help society move towards the delivery of sustainable development.

Stream 3b however occupies a thinner sub-section in the literature (see Publication 1 and [14]) that uses a living lab methodology to explicitly seek to move society towards sustainable development through user centred innovation.

7.8 Summary of the emerging metastructure to enable innovation at the university-industry-government nexus

The emerging metastructure to enable innovation at the university-industry-government nexus links the evolution of partnership structures, globalisation of the economy, society and environment and the observable changes in modes of knowledge production into one metastructure and this is presented in Table 7.7. Importantly it is reflexive of what is happening in actual partnerships reviewed for this thesis and is theoretically valid for binomial (between universities and industry) and trinomial (between university, industry and government) partnerships.

As discussed above the evolution in partnership development reflects the increasingly universal access to the internet and knowledge. However, whilst the evolution of partnership development might be influenced by factors external to the partnership it does not replace the importance of the top-down/bottom-up approach to partnership development endemic in the literature; indeed, as discussed (see Section 4.1) it builds upon that approach.

One important finding from combining the top-down/bottom-up approach to the evolutionary description of the creation of partnership development is that the top-down approach to partnership development (a finding in Section 4.1.2 and Publication 1) primarily focusses on the delivery of economic outcomes (with flow on benefits to economic actors in the economy), and that it is the bottom-up approach that seeks to deliver innovation in a manner that considers society (Stream 3a) and the three pillars of sustainable development (Stream 3b). This suggests there is a weakness in the partnership creation to properly address low carbon or sustainable development, which may be rectified by the application of the sustainable development goals as the core feature of the Triple Helix model.

Table 7.7 Emerging framework for the creation of intermediaries for innovation at the university-industry-government nexus

External stimuli	**Manifestation**	**Mode of knowledge production**	**Existing Model**	**Partnership stream**	**Response to sustainable development**
Globalisation of the economy	Deepening of the knowledge economy	Mode 1 Mode 2	Triple Helix	Stream 1 Stream 2	Economic
Globalisation of society	Democratisation of knowledge	Mode 2 Mode 3	Quadruple Helix[3]	Stream 2 Stream 3a	Economic, Social
Globalisation of the environment	Sustainable development goals	Mode 3	Quintuple Helix[3]	Stream 3b	Economic, Social Environmental

7.9 Integrating the metastructure and institutional framework

The proposed metastructure links partnerships for innovation, the globalisation of the economy, society and environment and the changes to modes of knowledge production. The institutional framework presented in Section 5.4 evidences the evolution of partnerships from an early to mature phase in terms of their ability to deliver Mission 1, 2 and 3 outcomes through open and co-creative partnerships in a manner that will be more predisposed to creating a low carbon and sustainable transition through innovation at the university-industry-government nexus.

[3] The Quadruple and Quintuple Helix are included in Table 7.6 as they are presented in the literature as a means of moving towards sustainable innovation. As discussed above both have significant shortcomings.

There is a close relationship between the phases in the institutional framework, the streams in the metastructure and the changing modes of knowledge production and this is presented in Table 7.8. It is through this affinity that the institutional and structural dislocation evidenced through the published works, and analysis presented in Chapters 4 – 7 are addressed through the metastructure within which the institutional framework resides.

Table 7.8 Relationship between proposed metastructure, institutional framework and modes of knowledge production

External stimuli	**Manifestation**	**Mode of knowledge production**	**Partnership stream**	**Institutional framework**
Globalisation of the economy	Deepening of the knowledge economy	Mode 1 Mode 2	Stream 1 Stream 2	Phase 1
Globalisation of society	Democratisation of knowledge	Mode 2 Mode 3	Stream 2 Stream 3a	Phase 2
Globalisation of the environment	Sustainable development goals	Mode 3	Stream 3b	Phase 3

7.10 Using the metastructure and institutional framework to enable low carbon transition at the university-industry-government nexus

The incorporation of the Sustainable Development Goals to the heart of the partnership structure, as proposed in Section 7.3, will help, in theory, to further the potential of innovation to deliver against a wider remit (as summarised in Table 7.9).

Table 7.9 Relationship between evolution of partnership streams and top-down/bottom-up partnership creation

	Location	**Partnership creation**	**Predominant contribution to sustainable development**
Stream 1	On campus	Top-down	Economic
Stream 2	Campus adjacent	Top-down	Economic
Stream 3a	Foot loose	Bottom-up	Economic and social
Stream 3b	Foot loose	Bottom-up	Economic, social and environmental

However, a more fundamental proposal, as evidenced through the research in this thesis, is to apply the institutional framework presented in Chapter 5 (see Table 5.3 and Section 5.4) to Stream 1 and Stream 2 partnerships. The institutional framework is based on evidence revealed in this research that open innovation and user engagement (enabled by the deepening of the knowledge economy, the globalisation of society and the change in modes of knowledge production) are the two elements that are common to living lab partnership structures (see Publication 1)

The institutional framework proposed in Chapter 5, based on interviews with practitioners and evidence from Publications 4 and 5, then develops a process for partners to apply these two traits to the development of existing partnerships. It is important to recognise that applying these traits to partnerships does not mean all partnerships will be living labs. Rather it is responding to the globalisation of society and the changes in knowledge production that is the impetus for the institutional framework (and this is discussed in Section 5.3).

7.11 Further research

The development of the metastructure can enable innovation at the university-industry-government nexus for the transition towards low carbon and sustainable innovation as it links external influences (globalisation of the economy, society and environment) to the core of the partnership development. This suggests that partnerships at some stage in their evolution will need to respond to the globalisation of the economy, society and environment and the addition of the sustainable development goals will provide evidence-based criteria to drive the development of intermediaries for innovation.

Much applied work will be required to test the metastructure described above, as well as the proposal discussed in Chapter 6 to develop best practice guides and manuals and start the process of delivering innovation at the university-industry-government nexus that will contribute towards the delivery of sustainable development.

Chapter 8 Conclusions and recommendations

This Chapter is structured as follows. Section 8.1 presents a summary of the research findings from each paper (see Table 8.1) to complement the presentation of research findings addressing the substantive question and the four sub-questions presented in Section 6.2 above. Section 8.2 then discusses the contribution of this body of work to the body of knowledge. Section 8.3 then recommends further research.

8.1 Summary of research findings

The body of research evidenced in this thesis forms five publications and Chapter 5 is summarised in Table 8.1.

8.2 Original and significant contribution

This thesis and associated publications (in Appendix B.1 to B.5) provides an original and significant contribution to the knowledge and understanding of low carbon and sustainable partnerships for innovation at the university-industry-government nexus in the following ways:

- Finds that top-down partnerships are focused on economic development whereas bottom-up partnership structures are more likely to be used to develop social and environmental innovation;
- Finds that there are no structural impediments preventing top-down partnership structures from being used to progress sustainable innovation, which suggests an institutional rather than structural problem;
- Develops a metastructure to enable innovation at the university-industry-government nexus consisting of three streams of partnership development: Stream 1: on campus; Stream 2: campus adjacent and Stream 3: living labs;
- The proposed metastructure to enable innovation at the university-industry-government nexus links the evolution of the development of partnerships for innovation to the globalisation of the economy, society and environment and the changing modes of knowledge production;
- Finds that there are institutional, rather than structural impediments that appear to mean that top-down structures are focused primarily on economic growth;

Table 8.1 Summary of evidenced findings from the body of work

Publication	Finding
Publication 1: A systematic literature review of partnership development at the university-industry-government nexus	• Builds on top-down/bottom-up analysis discussed the literature by demonstrating that the evolution of partnerships for innovation are driven by factors within the partnership but also by external to the partnership; • Describes three stages in the evolution of partnerships for innovation, which can be concurrent: namely the development of on campus structures; campus adjacent structures and living labs; • Finds only living labs (and derivatives) tackle economic and social issues; a smaller subset tackle economic, social and environmental issues; • Demonstrates that most research in the literature is grounded in economic theories; and • Developed a hypothesis linking evolution of partnerships for innovation, globalisation of economy, society and environment and changes in modes of knowledge production.

Publication 2
Business models for sustainability in living labs
	• Each business case was different due to the impact of three factors:
	  ○ The principles or purposes underpinning the SusLab's creation;
	  ○ How each entity responded to pressures or opportunities they faced during operation; and that
	  ○ In response to internal of external opportunities the business cases evolve over time
	• The article shows how the Tiple Helix model can be implemented locally and used on innovation that contributes to sustainable development; it shows how path dependence theory helps to understand the decision-making process to develop business cases, and it shows the value members of SusLabNWE place in being part of a wider consortium to assist with learning from experience and from doing

Publication	Finding
Publication 3 If living labs are the answer what is the question?	• Australian universities are weak, when compared to OECD counterparts at partnering with business for innovation; • Business is weak at partnering with Australia universities and as well as customers and suppliers; • Universities do not make effective use of their campuses to drive partnership development; • Rate of external change makes partnership development complex and uncertain; • Little evidence of the development of innovation partnerships to drive sustainable innovation at scale; and • Proposed that SDGs should be used as the framework to drive partnerships at the UIG nexus
Publication 4: A study of Australian Universities' collective response to climate science	• Three Australian universities committed themselves to a carbon reduction target in line with climate science. • For those 10 Australian universities who were required to report emissions data, their emissions rose by 4.63% between 2010/11 and 2014/15. • Together Australian universities were committed to investing over $1.5bn in capital infrastructure on their campuses in 2016. • Eight universities (20%) committed to using their campus' as living labs, or similar, to deliver teaching and research outcomes. • Revealed limited evidence of universities willingness to partner with themselves (to use their campus infrastructure to drive teaching and research outcomes)
Publication 5: Happy Homes – the relationship between homes and mental wellbeing	• Little in the literature reviewed addressing how to maintain or promote mental health in accommodation for the self-help/social support end of the mental health continuum • Needs to be a focus on transdisciplinary (to integrate all relevant disciplines) and translational (to develop practical interventions that work) research • Needs to be a focus on building resident to drive policy outcomes (current focus is on how to use building fabric to deliver for example climate targets) • Study shows the potential benefits of undertaking transdisciplinary translational research to UIG partners.

Publication	Finding

Chapter 5:
Innovation at the university-industry-government nexus. The case of Greater Curtin
	• Three themes emerged from the interviews:
	  ○ Theme one reveals that projects will evolve over time as the potential to deliver teaching and research outcomes is better understood and widely shared;
	  ○ Theme two reveals there is a lack of consensus between internal partners and external advisors around how to engage, integrate and showcase teaching and research outcomes into the project; and
	  ○ Theme three provides evidence that the university not maximising the potential of the project to drive Mission 1: teaching, Mission: 2 research outcomes, or Mission 3: engagement to develop partnerships for innovation;
	• Proposes an institutional framework to illustrate the potential to progress partnerships, overtime, to deepen the engagement of university and industry in the delivery of teaching and research outcomes through capital infrastructure projects.

- Finds that universities are not realising the full potential of campus redevelopment to further Mission 1: teach, 2: research and 3: engage priorities;
- Develops an institutional framework to help better understand the potential of campus redevelopment (Stream 1) to further partnership development, teaching and research outcomes and the commercialisation of knowledge to deliver economic, social and environmental outcomes; and
- Proposes the use of the sustainable development goals be used at the heart of the Triple Helix model around which the helixes revolve to further the adoption of sustainable innovation.

8.3 Further research

This thesis and the associated body of work has made a significant contribution to the theoretical body of knowledge on low carbon, or sustainable, transition through innovation at the university-industry-government nexus.

The work has also shown that top-down structures have not, in the literature reviewed for this thesis, led to the development of partnerships for sustainable innovation. This is a fascinating insight as both government and universities are highly educated and heavily invested in policy development, teaching and research into all the issues lying at the heart of sustainable development. Further research to understand this institutional issue is required.

The proposed metastructure (discussed in Chapter 7) and institutional framework developed in Section 5.3 help to address the largely elusive tension discussed above. The tension revolves around the formal, or informal, expression of the partnership between universities, industry and government and the actual partnerships that happen under the framework which leads to binomial partnerships even in a Triple Helix structure. The proposed metastructure starts to make sense of this incongruity but further research and exploration will be required.

Even so the apparent inability of Stream 1 and 2 partnerships to drive sustainable innovation needs to be better understood so that the metastructure can be further developed to help ensure local delivery of partnership development remains consistent with global initiatives. The metastructure is a start of this process but further work is needed.

There is a need for further applied and translational research to test the veracity of the theoretical developments proposed. This thesis has proposed an institutional framework for such applied research (particularly through Chapter 5 and Publication 5) which would help understand the potential to further sustainable innovation through campus redevelopment.

The proposal to use the sustainable development goals at the heart of the Triple Helix framework could be tested, possibly as part of the CSIRO's Responsible Innovation Future Science Platform to better understand how to deliver economically, socially and environmentally responsible innovation.

Publication 3 started – albeit unsuccessfully – to investigate the issue of decision making. It sought to apply Kahneman's [69] work on the psychology of human decision making to an institutional setting. This thesis has shown an institutional weakness that needs addressing. There is a rich seam of work that applies ecological concepts to the economy it would be interesting to see if the principles of human decision making can also be applied in an institutional setting. The early foray presented in Publication 3 suggests it might be fruitful work, but much further work is required.

The findings in this thesis would benefit from industry feedback into the utility of both the model developed in Chapter 5 and the metastructure proposed in Chapter 7 to help enable innovation at the university-industry-government nexus.

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Appendix A Extended literature review

This Appendix provides an extended literature review for this thesis and for each publication (Appendix B.1 to B.5). It provides a detailed view of the existing literature within which this thesis resides. The extended review provides an exploration of the literature that relates to the rise of the knowledge economy, the changing role of knowledge to drive economic development; the importance of exogeneity to economic theories; changing modes of knowledge creation, the changing role of universities as creators of knowledge, the importance of collaboration and partnership as well as issues specific to the theory of partnership development at the university-industry-government nexus. Table A.1 provides an overview of the relevance of the literature to the overall exegesis discussion. A synthesis of the key issues is provided in Chapter 2.

A.1 The changing role of knowledge in the economy

Since the birth of the modern economic system knowledge has been a key factor in creating wealth and delivering economic growth. Economic systems are based on exploiting knowledge to create goods or services. There is no knowledge free economy. It was this exploitation of knowledge and then technological diffusion that led to five technological transformations (see Table A.2) that have driven economic growth and prosperity since at least the 18th century [15].

The point about the economy is that economic growth increasingly depends upon the exploitation of knowledge for the next wave of economic growth [97]. Such an economy has been referred to as post-industrial [15], post-Capitalist [114], learning economy [24] and knowledge economy [115]. In this thesis the term knowledge economy is used.

In a knowledge economy there is a greater reliance on knowledge than physical or natural resources to increase economic activity. A knowledge economy is defined as “the production and services based on knowledge intensive activities that contribute to an accelerated pace of technological and scientific advance as well as equally rapid obsolescence” [115].

The term knowledge economy covers a wide variety of activities, and the literature reveals three broad strands of research. The first is focused on the rise of

new science-based industries, in the early to mid-20th century where cycles of innovation were increasingly rapid and would herald a new product or service. The rise of services, and intangible goods and information was increasingly common [116]. This era saw the formalised development of a professional services industry [115]. Such industries are information rich but the role of knowledge in furthering economic is subject to much debate [117].

Table A.1 Relationship between the literature review, research questions and the exegesis discussion

Section	Literature reviewed	Research question	Thesis narrative
Appendix A	Changing role of knowledge in the economy Changing role of universities A changing climate Innovation and sustainable development Economics of innovation: the rise of partnerships for innovation	How can universities, industry and government together drive low carbon innovation and transition?	• Knowledge is becoming an increasingly important driver of economic growth • The process of innovation is evolving • This has led to the creation of different partnership structures • The focus of innovation is economic growth
Section 2.2 and Appendix A	Partnerships for innovation – models of partnership at the UIG nexus	Which partnership models at the UIG nexus have been successful to deliver innovation?	• Increasingly commercial exploitation of knowledge depends upon a partnership between two or more entities • The focus is the delivery of commercial success and economic growth

Section	Literature reviewed	Research question	Thesis narrative
Section 2.3 and Appendix A	Partnerships for innovation – the creation of hybrid organisations	Which factors promote or limit partnership development for a low carbon future?	• Partnership structures are evolving from a top-down/ bottom-up approach • Top-down approaches are an organisational response to the exploitation of knowledge • Bottom-up structures are more likely to address economic, social and environmental issues
Section 2.4 and Appendix A	Partnerships delivering economic, social and environmental outputs	Which partnership models at the UIG nexus have been successful to deliver low carbon and/or sustainable innovation?	• Partnerships that give voice to public interest are more likely to drive local low carbon outcomes • However, there is little evidence of these partnerships delivering across the sustainable development goals

The second stream of research surrounds the knowledge intensity of industries. The argument runs that knowledge intensive industries create new products and services increasingly rapidly and this gives rise to productivity gains and economic growth. However, there is a paradox as the productivity of particularly the service sector has stagnated whilst the investment in technology has increased by orders of magnitude [118, 119].

Table A.2 Technological transformations since the 18th century

Date	Technological transformation	Technological diffusion
1770 - 1800	Move from a dependence on charcoal to coal	Development of transport systems and early mechanisation
1830 - 1850	Application of steam technology to textile and transportation	Diffusion of stationary and moving steam engines
1860 - 1900	Steel, internal combustion engine, electrification and communication. Expansion of the chemicals industry. Sharp increase in manufacturing productivity.	Exploitation of oil and coal to create electricity. Creates the potential for long distance communication and many new industries.
1930 - 1950	Synthetic materials and development of electronics. Emergence of consumer demand	Diffusion of technologies and mass production of electronic and 'white' goods.
1980 -	Convergence of computers and telecommunications	Post-industrial economy (see below)

The third stream of research relates to the role of innovation within firms and is more managerial in nature. This stream of research started with Taylorism but, thanks to Drucker [114] focused on the fifth, or main factor of production – knowledge. He posited that the economy – certainly since the end of World War 2 was increasingly knowledge based. The importance of knowledge to society for economic development has been a policy aim of Government since the 1940s – an early example in the USA is the Bill of Rights which gave every returning serviceman financial support to attend university [120].

Drucker [114] identifies knowledge as being applied to knowledge, which he defines as management. But he also recognises the importance of applying knowledge systematically to define what knowledge is needed, what is feasible and what has to be done to make the knowledge effective. This he refers to as a management revolution, and this thesis is grounded in that revolution.

A.1.1 Knowledge as a management revolution

Before the advent of the internet Drucker [1, 114, 121] foresaw the need for educated people to be citizens of the world and foretold the conflict between holders of knowledge who wish to practice their knowledge and managers who see knowledge

as a means to the ends of organisational performance. He sees them as representing different poles on a continuum rather than contradictions and he sets out how each need the other.

The intellectual, unless counterbalanced by the manager does his own thing; the manager's world becomes "stultifying and bureaucratic" without the offsetting influence of the intellectual. The relentless rise in the importance of knowledge to individuals, organisations and society gives rise to several tensions [114]:

- Communities need for stability, but organisations need to destabilise;
- An organisation's need for autonomy and society's stake in the common good; and
- The tensions between increasingly specialised specialists and the performance of the team.

He predicted that all of these will be central concerns for years to come. It is the bringing together of these issues that is the essence at the heart of this thesis. How can knowledge be created, used and applied to further the interests of humanity?

> *"The challenge that faces us now, and especially in the developed, free-market democracies such as the United States, is to make the pluralism of autonomous, knowledge-based organisations redound both to economic performance and to political and social cohesion*". [114]

A.1.2 Realigning the role of universities, industry and government

The importance of the knowledge economy for the next wave of economic growth has led to an increased focus by Government policy makers, universities as well as businesses on the development and economic exploitation of knowledge. This has led to an evolution in the role of the university in society and it is one that continues to evolve. Universities have existed for 800 years, and the current realignment is the beginning of only the third such change in their history (see Table A.3 which is developed from [7, 39, 122]) and it is associated directly with the changing role of knowledge in society and the economy [7].

Table A.3 The evolving state of the university

Date	Principle influences on the university	Main function of university	Main outputs	Mode of knowledge production
1170 – 1330	Church	Education	Lawyers, priests and medical doctors	
1330 - 1830	Church and state	Education	Lawyers, priests, medical doctors and civil servants	
First academic revolution				
1830 - 1980	State	Education Research	Professions, Civil Servants, Enterprise Pure research Applied research	Mode 1[4] research
Second academic revolution				
1980 -	State and enterprise	Education Research Engagement	Key skilled groups Pure research Applied research	Mode 2 & Mode 3 research

A.1.3 Entrepreneurial universities

The changing role of the university is a response to the intensification of knowledge as a driver of economic growth. This has been recognised by government and has led to the emergence of entrepreneurial universities [8, 39] where the interaction between academia and industry was encouraged as well as an evolution in the form of research undertaken (see Table A.3).

Universities exist today to do three things: teach, research and engage (Publication 3, [123]). Universities continue to evolve in response to their external environment (deepening of the knowledge economy) and internal environment (commercialisation potential of research). America and Europe had different drivers for change. In America

[4] There is debate about whether Mode 1 precedes Mode 2 knowledge production or not. It is not for this thesis to resolve the question. However, in the university context the institutionalisation of disciplines around 1800 will have led to Mode 1-type knowledge production. Prior to institutionalisation it is reasonable to assume that knowledge production was more in line with Mode 2.

it was a largely bottom-up transformation with universities understanding the potential value of their research; in Europe is has been a largely top-down process with universities being given policy incentives (through funding inducements or cuts) to commercialise research. As such an entrepreneurial, or corporate university functions primarily to promote economic development (Publication 1 [20]) and works towards the capitalisation of knowledge [39].

Increasingly with the emergence of massive open online courses (MOOCs) and online platforms an entrepreneurial university can now apply the ethos of entrepreneurism to all its learning activities (teaching, research and engagement) and not just research. Universities have had to develop new skills, processes and functions (see Table A.4 which is adapted from [93]) to accommodate the evolution to entrepreneurialism [47]. This comes in the form of intellectual property agreements, conflict of interest processes, technology transfer becoming a new function and a blurring of the lines between where universities end, and businesses start [39]. This thesis is placed at the boundary between university, industry, government and society.

A.1.4 Changing modes of knowledge production

As universities have become more entrepreneurial so too has government, innovation processes and as a result methods of knowledge production.

Knowledge production has become increasingly distributed - a fact that was initially recognised in 1963 [124]. That process has not slowed but rather accelerated leading to a globalisation of knowledge production [125]. This globalisation has led to changing modes of knowledge production.

Table A.4 Aspects of learning impacted by transition to an entrepreneurial university

Aspects of learning	Impact
Teaching Research Engagement	Entrepreneurship development in teaching and learning
	Pathways for entrepreneurs
	Organisational capacity: people and incentives
	University/industry – external relationships for knowledge exchange
	International relationships (academic, business and government)
	Leadership and governance
	Impact realisation (KPIs)

Mode 1 knowledge production is the type of research that was conducted when universities started to undertake research. It is discipline based and produces theoretical knowledge [19]. Mode 1 research is still relevant today and is referred to as fundamental research [20].

Mode 2 knowledge production is transdisciplinary. In Mode 2 knowledge production there is a continuous interaction between theoretical and applied elements of research and practice so that one informs the other. The research is not fundamental in nature and is characterised by application or use in practice. Typically, more researchers are involved than in Mode 1 from a range of academic disciplines [19]. "Mode 2 creates a novel environment in which knowledge flows more easily across disciplinary boundaries, human resources are more mobile and the organisation of research more open and flexible" [19]. It is also distributed knowledge; distributed between partners but also geographically [124] and this spatial spread is also contributing to the globalisation of knowledge production [125].

Mode 3 knowledge production is a development from Mode 2. The key conceptual development is that it is a multi-level innovation ecosystem [126]. It goes wider than transdisciplinary as it includes various subsystems that when drawn together enable people, culture and technology to interact to innovate across scientific and technological disciplines and public/private sectors [31]. It emphasises a knowledge systems perspective [127]. It has been argued that Mode 3 combines mode 1 and mode 2 by undertaking basic research in an applied manner [127]. Mode 3 knowledge production has been referred to as open innovation democracy [128] or the democratisation of knowledge [16]. See Table A.5 for a summary.

Table A.5 Modes of knowledge production

Knowledge Production	Knowledge production elements	Innovation process
Mode 1	Discipline based; fundamental	Linear
Mode 2	Transdisciplinary; applied and distributed between partners	Non-linear
Mode 3	Transdisciplinary; applied; distributed and democratic	Multi- level ecosystem

The change in the modes of knowledge production is significant for this thesis for two reasons. Firstly, it is easy to see how conceptually knowledge production can not only transcend disciplinary boundaries but also organisational boundaries. The focus is on the production and sharing of knowledge rather than who creates or owns the knowledge, the focus is on the use of knowledge. This is what von Hippel [16] refers to as the democratisation of knowledge.

The second flows from the first and it is the link to the nascent responsible research initiative (discussed further in this section) where the EU, USA and more recently Australia have started a process to engage society on the merits of research investment in order to reduce the risk of research moving society in a direction that is contrary to the wishes of broader society [106]. These initial moves towards 'Responsible Research and Innovation' reflects the further development a process between universities, industry and government where grant applications increasingly engage funding bodies in language that resonates with the policy, or research impact, or business drivers rather than the vernacular of the academic discipline. The shift to Mode 2 knowledge production was inevitable in a deepening knowledge economy where research funding is competitive and needs to have an economic (and increasingly social) return. Indeed, there is an emerging stream of work on what is referred to as *Globalisation 2* [3] which is looking to the engagement of society in globalisation in a transdisciplinary manner consistent with open science and innovation.

A.2 Innovation and government policy

The importance of commercialising knowledge as a route to economic growth is increasingly recognised by international development organisations (for example [47]) as well as government (in Australia see for example [49] and [129]).

In the wake of the 2008 financial crisis innovation has become the focus of Government attention due to its potential to generate economic growth, new jobs [47] and to "seize" the next wave of economic prosperity [5]. To do this there is a need to create new forms of partnerships to exploit the potential of new knowledge [92] and vertical, or silo-based policies need to be complemented by a horizontal or whole of government approach to innovation [129] and the development of a more systematic ecosystem approach to innovation [47]. However, despite the emphasis on the

importance of innovation, the OECD gross expenditure on research and development in 2008 – 12 at 1.6% was half of the rate it was between 2001 – 2008[5]. China's expenditure on research and development doubled over the same timeframe [93].

A.3 Australian innovation policy and performance

Australia launched its National Innovation and Science Agenda in 2015 [5]. It presented a whole of government approach to innovation and stressed the importance of innovation to "seize the next economic wave" to keep Australia competitive, relevant and to maintain standards of living [5]. The *Agenda* presented four pillars that provided the framework for Australia's innovation policy: culture and capital; collaboration; talent and skills; government as an exemplar. It foreshadowed an active role for government in the policy space and the collaboration pillar of the policy reflects the importance of developing partnerships to effectively exploit knowledge.

> *"There is an ever-present imperative to capture the commercial value of our research endeavour for our future wellbeing" Alan Finkel,* (in [130])

The Australian government recognised that the rate of collaboration between research and industry sectors in Australia was the lowest in the OECD [5, 93] in the bottom half of the OECD [131] and remains weak [50]. Australian industry is generally weak at collaborating for innovation, even though public research funding in universities at a level that is higher than the OECD average [93]. The collaboration for innovation that does happen is mostly domestic with customers or suppliers. Of those firms that do collaborate 25% do so with a firm within their ownership structure [50]. Collaboration with publicly funded researchers is limited standing at 2% of patent applications [50]. However, even though the percentage is low it is estimated to generate $10.4bn in 2018 generating 30,000 full time jobs, although this is 30% lower than the United States or Israel [51].

This relative weakness at collaboration stands in contrast to Australian research output, of which 90% is at or above world standard [51] and with a ranking 23rd in the world in the WIPO Global Innovation Index [52] making Australia an innovation leader [50]. Australia performs well in knowledge creation but relatively poorly in translating

[5] Note – this represents 1.6% of Gross Domestic Product; it does not mean that spending on R&D was halved, but rather the share of spending on R&D did not increase at the same rate as GDP

this knowledge into new products or other innovations [49]. This has been recognised by Innovation and Science Australia who in 2017 made improving the collaboration between universities and industry one of their 5 imperatives [54], which at the time of writing the Australian government is consulting upon [49].

A.4 A changing climate

Anthropogenic greenhouse gas emissions (GHG) are rising and forcing the climate to change [132-135]. These changes are happening in every region and across the global climate system [134]. These changes will involve increasing heatwaves, more intense storms, changing rainfall patterns, increased (and increasingly frequent) flooding, permafrost thawing, loss of seasonal snow cover, melting of glaciers and ice caps. The impacts of increasing concentrations of greenhouse gases in the atmosphere are significant and long term (ranging from centuries to millennia) [134]. Carbon dioxide is the main driver of climate change [134] and there is a 'near linear' relationship between cumulative anthropogenic carbon dioxide and the global warming they are causing [134]. Concentrations of carbon dioxide have increased by 46% since the industrial revolution and is now at a level that has no equivalent in at least 800,000 years.

It is "unequivocal" [134] that human influence has warmed the atmosphere, ocean and land. This has led to heatwaves, bushfires, flooding and weather extremes. In Australia 2019 was the warmest (1.52^{o}c warmer than previous warmest year) and driest year (11.7% drier than previous driest year) on record [136].

Further, in Australia the 2019/2020 bushfires are the largest on record burning over 10m hectares of land [137] and burnt an unprecedented area of temperate forest, woodland and shrubland across south-eastern Australia [138]. Such mega-fires are increasing in number and severity [139] and climate change making the conditions more conducive for such fires [138]. The cost of the fires is estimated to be $100bn with 832 native vertebrate fauna impacted of which 21 were already listed with extinction and 70 species lost over 30% of their habitat [140].

A.4.1 Sustainable development - society's response to a changing world

Humankind's impact on our natural environment has long been recognised across a range of indicators from a rising population, to increased resource usage and changing

of the landscape (see Table A.6 from McNeil in [141]). The current generation is not unique in its efforts to change nature to its will [142]; it is just that the scale of the impact is epoch making which has led to calls for the Anthropocene to be approved as a subdivision of geological time [143].

The impact of these changes on the economy, environment and society has long been debated. Malthus published his essay on the principle of population in 1798 concerning the exponential growth of the population outstripping the linear growth of food production. In 1972 the Club of Rome published "Limits to growth" [96] looking at the issue of exponential growth in a finite world. At the same time the United Nations hosted the United Nations Conference on the Human Environment in Stockholm, Sweden[6] in 1972. The conference created institutional change (such as the creation of the UN Environment Program) but there was inaction over implementation of the agreed program. However, it did lead to a greater focus on how the economy, environment and society interact.

Table A.6 A partial record of the growth and impacts of human activities during the 20th century

Impact	**Increase factor 1890s to 1990s**
Human population	4
World urban population	13
World economy	14
Industrial output	40
Energy use	16
Coal production	7
CO_2 emissions	17
SO_2 emissions	13
Water use	9
Marine fish catch	35
Cattle population	4
Irrigated area	5

[6] The conference was hosted in Sweden as it had suggested in 1968 that a conference should be hosted to focus on human interactions with the environment.

The issues raised were sufficiently serious to lead to the publication by the United Nations' World Commission on Environment and Development of "Our Common Future" [144] which in turn led to the UN hosting the World Summit of Sustainable Development in 1992, 2002 World Summit on Sustainable Development (Johannesburg) and the UN Conference on Sustainable Development in 2012.

Sustainable development is defined as "development that meets the needs of the current generation without compromising the opportunity of future generations to meet their own needs" [144]. The definition is widely accepted (although there are many variations [145]) but the real issue is not with the definition but with what does good look like [146]? This is an issue that has been resolved with the unanimous adoption in 2015 of the 2030 Agenda for Sustainable Development [147]. The 2030 Agenda for Sustainable Development set out 17 sustainable development goals (SDGs) (see Table A.7) with 169 associated targets for economic, social and environmental objectives [147].

Table A.7 United Nations' Sustainable Development Goals

It therefore defines for the first time what good looks like and defines means of implementation to set humanity on a sustainable trajectory [148]. In Australia the sustainable development goals have been described as "a true global blueprint for a sustainable future for our planet, our communities, our families and our economies" and a "contemporary manifestation of the 'fair go'" [149].

The SDGs are intended to stimulate action - through a collaborative partnership – from 2015 – 2030 to promote the interests of people, planet, prosperity and peace through a revitalised Global Partnership for Sustainable Development [150].

A.5 Innovation and Responsible Research and Innovation

The literature on innovation is diverse and there are many definitions of innovation [151]. In developing a multidisciplinary definition of innovation Baregheh et al [152] lists 60 definitions of innovation and proposes an integrative definition of innovation: "Innovation is the multi-stage process whereby organisations transform ideas into new/improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace" [152].

The OECD define innovation as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations". And the also OECD defines four discreet forms of innovation (see Table A.8 [153]).

But as Drucker [154] points out innovation is not limited to an organisational response, but it can be practiced by individuals as well as commercial, not for profit and public sector organisations. Irregardless, at the core of innovation are the concepts of improvement, newness and spread of ideas or technologies for some form of reward. In terms of reward much of the literature is predisposed towards economic reward (Publication 1; [12]), but there is an emerging stream of largely European research looking at 'responsible' innovation where reward can be a mixture of economic, social or environmental outcomes [155].

Innovation itself is a process that starts with an idea (for a new process, product, good or service) and ends with getting some form of reward for that idea. The route between idea and reward conceptually is linear, but increasingly it is a non-linear process (Publication 1, [12, 13, 31]).

A.5.1 Responsible innovation

Responsible innovation is an emerging stream of research from Europe. It is an approach to research and innovation that looks not only at the research but also the

likely impact of the research and consequent innovation on society to foster a design that produces research and innovation that society is comfortable with [156]. The area is emerging and strategic in nature. It is currently focused on the acceptability of science and technology research and innovation to wider society. The research is at a high level looking largely at focused ethical issues and the social acceptability of the proposed research and innovation [157].

Responsible Research and Innovation is part of Europe's drive for the creation of a research and innovation policy to meet the needs of society by engaging society using inclusive participatory approaches (see Table A.9) [37]. It is the result of a continuation of the pursuit of "open science" in the European Union and as such it is progression from open access [105]. For the EU, Responsible Research and Innovation is about making sure that research and innovation proceeds in an inclusive manner and reflects upon societal needs, moral values [37] and has societal relevance [158]. It is therefore knowledge creation at the Mode 2 or Mode 3 interface.

Table A.8 OECD's 4 types of innovation

Type of innovation	**Description**
Product innovation	A good or service that is new or significantly improved. This includes significant improvements in technical specifications, components and materials, software in the product, user friendliness or other functional characteristics
Process innovation	A new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software.
Marketing innovation	A new marketing method involving significant changes in product design or packaging, product placement, product promotion or pricing.
Organisational	A new organisational method in business practices, workplace organisation or external relations.

Responsible research and innovation (RRI) goes beyond complying with ethics requirements and research codes of practice [105]. It takes researchers into a space where the research partnership needs to demonstrate and discuss with society a societal benefit (however defined) from the work [159]. As such the science needs to be contextuated [3] and the benefits debated. RRI is about developing individualised

processes to enhance the 'value, benefit and impact that can be created from science for society' [105].

The EU [37] foresees that RRI will ultimately strengthen the knowledge economy (see Table A.9). This move to open science includes the commercialisation of science [160] and the partnership required to commercialise the research [161]. Currently the preponderance of the emerging research is on 'upstream' management of research and innovation partnerships with less attention to 'downstream' implementation and governance [161]. This thesis is concerned with downstream governance issues.

A.5.2 Responsible innovation and Australia

In Australia, Responsible Research and Innovation is known as *Responsible innovation* and CSIRO created a Responsible Innovation Future Science Platform in 2019. The platform's vision is to "ensure responsible science and technology is designed and delivered for the benefit of all Australians" [162]. The platforms' aims are to:

- Assess the potential risks, benefits and uncertainties of future science and technology; and
- Ensure socially responsible science and technology is delivered for all Australians.

Table A.9 European RRI - 6 streams of work

Stream	**Description**
Choose Together	Co-creation of a response to the grand challenges facing humanity
Unlock the full potential	Ensure that all parts of society are engaged and included (in universities and participatory panels)
Creative learning and fresh ideas	Sharing of ideas and responses through the engagement of all societal actors
Do the right "think" and do it right	Change the view of ethics from being a constraint to helping to deliver high quality relevant research
Share results to advance	Make science knowledge as open as possible and actively share results
Design science with and for society	Development of governance structures to develop responsible research and innovation

Responsible Innovation is a Future Science Platform with the CSIRO. It is aligned with the European approach seeking to encourage public participation in the design of science. Similarly, it is focused on the future of science and technology in both basic and applied research – it seeks to assess the potential risks, benefits and uncertainties of future science and technology [162]. However, the premise behind *Responsible Innovation* in Australia is to make the research and innovation socially acceptable and deliver benefits to society [105]. It is important to note that this does not necessarily mean that the research or innovation will be sustainable or contribute to moving society towards the achievement of the sustainable development goals but rather that a discussion has taken place with society about the benefits of the research to society.

A.6 Economics of innovation – the rise of partnerships for innovation

Classical economics holds that a nation will export goods in which it is relatively well endowed [4]. However, a nation creates, rather than inherits the most important factors of production such as skilled workforce or a strong scientific base. This reality, demonstrated by Porter [4], demonstrates how nations drive competitiveness not just through the efficient allocation of resources but also through investment in critical areas of non-tangible factors of production.

Driving innovation to enhance the competitive advantage of the nation is therefore a key economic policy issue in both macro and micro-economics. At the macro-level until the 1990s it was assumed that technological progress happened as a result of some external force [22] - possibly akin to the invisible hand [163]. Progress happened, argued classical economists as the result of competition for ideas and the interaction between the factors of production that drove total factor productivity [119].

In an economy where economic success is based on the exploitation of knowledge if that knowledge is exogenous (even if not unimportant [164]) then it leaves an unmanageable and significant weakness in economic theory especially as knowledge and skills are unevenly distributed within regions and nations [22]. Further, if economic growth is now not the result of efficient allocation of resources but rather exploitation of knowledge then the classical approach is not helpful.

An alternative view, developed during the 1980s, was that growth happened as a result of a network of decisions made within an economy. In the endogenous growth theory [117] innovation, or technological change happens because of a deliberate decision by individuals and these decisions are influenced by policy measures [117].

At the micro-economic level innovation and the ability to serve a customer's needs over the longer term determine profitability of a business [165]. The problem is to take an issue that is in essence is a micro-economic problem (different skills being appropriate to different technologies and different geographies) to a national or macro policy context to help drive economic growth.

The key issue here is not the neo-classical efficient allocation of factors of production but the ability of the individual to learn [22] and for society to invest in specialisation [4]. Lundvall [22] argues that the efficient allocation of resources will mean that an economy may grow in the neo-classical sense in the short term by driving out inefficiency, but in the long run efficient allocation of resources will lead to stagnation. The key to future growth will be innovation. But growth will be driven by innovation rather than knowledge *per se,* which takes us straight back to Drucker [114, 121]. The key issue here is that it is the ability to utilise knowledge that drives economic growth rather than knowledge itself. So, the driver of growth will be the ability to learn, as knowledge stagnates. In the same way efficient allocation of resources will drive growth in the short-term; utilisation of a fixed set of knowledge will drive economic growth until the knowledge has been used up. This argument is an economic argument that does not consider social or environmental concerns. However, it is a useful eulogy as it helpfully demonstrates the economic and broader policy rationale behind knowledge and innovation as key drivers of economic growth in modern capitalism.

Consideration of the policy implications brings into focus the issue of institutions. Institutions embody the norms, habits and rules of society [22]. This is particularly true for a knowledge economy based on the exploitation of knowledge for economic growth and rising standards of living. This pathway to growth creates fundamental uncertainty [22] and consequently the role of institutions (as the holders of societal norms) becomes increasingly important (see Table A.10). They become increasingly important because of the break with previous neo-classical assumptions

of perfect knowledge and decision making. It is the addition of social capital into economic development policy that is important [29, 166].

Social capital is “an instantiated informal norm that promotes co-operation between two or more individuals” [29]. But in earlier work he defined social capital as a moral community: that allows members of a given society to trust one another and cooperate in the formation of new groups and associations [167]. In terms of economics the importance of social capital is to reduce transaction costs (thus it helps with the efficient and productive allocation of resources); it is central to the development of trust, but like trust it is difficult to generate with public policy [166, 168]. Interestingly globalisation, as a carrier of ideas, can create social capital [29] and influence through the reduction of proximity even the most powerful states [169].

This development of innovation as a key to the future of economic development led to the development of the concept of national innovation systems [20, 22, 23]. National innovation system research is work looking into the different innovation infrastructure in different countries. It augments the work on competitive advantage [4] by describing the difference in innovative capacity between countries [23]. There is debate about whether a national system of innovation makes sense in an increasingly globalised economy, but the nation state is still the level at which policy is made and developed, welfare levels determined, and the macro-economic context is set [22]. Indeed Porter [4] argues that the nation state is becoming more, not less important. For the purposes of this exegesis the argument is increasingly moot, but the nation state is still able to develop policies to compete on a multi- or international stage.

Table A.10 Lundvall's [22] four types of institution important for learning and innovation

Type of institution	Example	Importance of the issue
Time horizon of agents	Short term time horizons in some western economies	A short-term mindset will be appropriate for the exploitation of some, but not all knowledge
The role of trust in the economy	Loss of trust through nationalisation or transition from a centralised to market led economy	Trust can be replaced by strong (but expensive) legal institutions
Rationality of agents	Much economic theory assumes that decision making is rational and perfect	The exploitation of knowledge for economic advancement is not an individual endeavour based on instrumental rationality. It is based on communicative rationality
Forms of authority	Trust and authority are necessary if learning is to be efficient	The basis of authority (age, trust, financial) maybe a key determinant in the form and style of innovation.

The key message to emerge from the national systems of innovation school is the development of thinking that differentiates (but also incorporates) the concepts of tangibility and reproducibility (see Table A.11) [22]. Tangible resources are reduced in the economic process (e.g., consumption of energy and materials) but non-tangible resources (e.g., intellectual capital or knowledge) can be increased in the process [24] It also was the point at which the linearity of innovation processes was questioned.

Linear innovation systems (see Table A.11), inspired by Bush [25] and based on Mode 1 knowledge production and the basis of much government policy post-war, are based on demand pull or technology push. But they fail to adequately account for the complexity of the innovation process or, importantly the complexity of the network of relationships and more importantly was insufficient, alone, to create an effective transfer of knowledge to the marketplace [20]. However, this does not mean that a linear model of innovation is redundant, but rather a non-linear model is a useful addition to the theory [21].

Linear models of innovation suited the institutional paradigms of post-war reconstruction. Knowledge (rather than innovation) was less ubiquitous and institutional demarcation was in place (see Section 2.2.1). In America the linear model became less structured with the creation of land universities and the passage of the Bayh-Dole Act [11]). This period also represented an era where the timelines between knowledge creation and innovation were shortening [26] and an increased focus on the productive use of public resources.

This led to new growth economics based on endogenous growth and a more transdisciplinary approach to economic policy development. It also led to a clearer understanding of the physical limits to growth [96] as well as the non-traded interdependencies, such as social capital development [22]. Lundvall [22] argues that the development of evolutionary economics makes the challenge to sustainability clear: left unimpeded market forces will erode the basis for economic growth.

Table A.11 Resources fundamental for economic growth - combining the tangible and reproducible dimensions

	Reproducible resources	Non-reproducible resources
Tangible resources	Production capital	Natural capital
Intangible resources	Intellectual capital	Social capital

Evolutionary economics or not, the importance of the national systems approach is twofold. One is that it holds social capital development (or depletion) close to its heart. It is the deployment of social capital that reduces transaction costs, creates (or depletes) trust and puts the social dimension at the heart of innovation. The second is the construction of a system of innovation, based on a social construct, that can evolve over time (an endless transition [20]).

These two dynamics are the key to understanding the development of partnerships for innovation and what distinguishes it from previous models of innovation. Through this lens the Triple [27], Quadruple [21] and Quintuple [32] Helices are an extension of, or evolution from, the national systems approach as they retain a social construct at their core but take an evolutionary systems approach. The establishment of innovation around

a social construct can be seen, in part at least, as the start of a development of a non-linear approach to innovation.

Within a national system there are also different styles of innovation with each style representing economically relevant knowledge [24]. The styles of innovation are an important concept as they again reinforce the social dimension (see Table A.12 based on [24, 30]) as well as the start of a distinction between the national (or macro) and the local (or micro) formulation and implementation of innovation policy.

Table A.12 Styles of innovation

Style	Description	Source of knowledge	Ease pf reproduction
Know-what	Fact based information	Internet, lectures, books	Easy
Know-why	Principle, theoretical or legal law-based information	Internet, lectures, books	Easy
Know-how	Knowledge developed by and kept within a team/firm	Practical experience	Hard (cannot be removed from human and social context)
Know-who	Who knows what and what to do	Social practice	Hard (cannot be removed from human and social context)

A.7 Partnerships for innovation

The systemic approach to innovation offers the benefits of a solution where the sum of the parts does constitute the whole [20]. Left to themselves none of the actors can create a modern competitive economy, take care of the sick or protect the natural environment. It is through the interplay of the participants within the system that these issues can be resolved. It is not an economic solution but rather a quality-of-life solution where decisions are taken to balance and integrate the competing needs of the economic, social and environmental goals.

A.8 Triple Helix model

The deepening of the knowledge economy, where knowledge provides competitive advantage, creates a new imperative for universities. That imperative is

certainly twofold: one is to continue to develop and create new knowledge but importantly to engage with business and government to seek economic rent from knowledge development. This new interplay led to the development of the Triple Helix model (see Figure 2.1 to Figure 2.4, and a fuller explanation in Table A.13) and the beginning of an evolution of a systems approach to the development of a national or multi-national innovation process [27]. The Triple Helix is a model of interactions between wealth creation (industry), knowledge production (universities) and regulations (government) [170] where each helix represents a knowledge sub-system connecting with each other in a spiral (and at a local, regional, national or super-national scale) [33].

Whilst all variants of the Triple Helix partnerships have the same actors (universities, industry and government) not all are created equal. There are several variants, and these are described in Table A.13 (which is developed from [20, 171]).

The Triple Helix model is useful because it caters for at least three different sources of national variation:

- National industrial sectors are varied and different (for example see [4, 27]);
- Different technologies induce different forms of innovation; and
- Systems of innovation integrate the various functions in a manner that is suitable to the local situation.

These variations can be seen as both exogenous (that is to say they are the result of competitive activities) but within the Triple Helix they are also endogenous (as they are the result of institutional settings [27]). With the evolution of the Triple Helix those endogenous settings are working together resulting in a spiral pattern of linkages [27]. The model embraces the traditional didactic relationships and takes account of the expanding role of knowledge which due to the reflexive nature of human (and thereby organisational) behaviour generates new structures within (for example research centres and institutes) and between each of them (for example hybrid organisations) [38].

Within the Triple Helix model governance arrangements are also changing and becoming increasingly reflexive. They change their positions according to institutional constraints and opportunities. As such governance becomes a nested structure of reflexive controls [38]. What is less clear is what the reflexive controls seek to achieve?

In the literature there are several outcomes of innovation that emerge to drive the delivery of innovation (see Table A.14).

Part of the strength of the Triple Helix model is that it remains relevant in times of uncertainty. This is the key to reflexivity – institutions react according to their best interests (or mutual selections [38]) but within a broader framework. Therefore, the Triple Helix is an evolutionary model – it evolves along a pathway that is considered by the partnership as acceptable according to the self-interested decisions (or institutional constraints and opportunities [38]) of the interested partners (wealth creation, knowledge and regulations [170]). These self-interested decisions need to help move towards an outcome that can never truly be achieved. In many respects it therefore truly represents an infinite triple helix. This evolution is expected in the Triple Helix model. Triple helices are complex and potentially unstable (cf Drucker and Section 1.2) and complex dynamics are expected to occur [27] but the model is sufficiently complex to accommodate chaotic behaviour [20].

Table A.13 The evolution of the Triple Helix model of innovation

	Description	**Example**
Triple Helix 1: Statist	Nation state encompasses academia and industry and directs relations between them	This might be the case in former Soviet economies or the economies of former eastern Europe. But it can also be recognised in an economy that has a strong government who can direct or incentivise behaviour
Triple Helix 2: *Laissez faire*	A *laissez faire* model. Separate institutional spheres with strong boundaries between them	Exemplified by economies that have clear rules about the roles of different organisations (e.g., Sweden and USA in the 1990s)
Triple Helix 3: Overlapping or balanced	Generation of knowledge through the overlapping of institutional spheres. Developed in recognition of the various different forms of government, business and university.	Adopted by countries with an approach that is driven by delivery of desired outcomes.

	Description	Example
Triple Helix 3: Social structure	New organisational innovations arise from interactions amongst the three helixes.	In a democracy government represents the views of the people. However, in a knowledge democracy the people can represent their own interests and therefore need to be engaged (see Section A5 on responsible research and open science)
Triple Helix 4: Delayed Government-led model	Identified in China this model is led by university and industry, but Government involvement only happens later, but then takes over	Tongji Creative Cluster in China – an industry/academia initiative that then was subsumed into central planning

A.8.1 Theoretical foundations of the Triple Helix model.

The Triple Helix model is based on the triadic tradition [42] of the social theories of Simmel, Marx and Webber [172]. At the heart of the triadic tradition is acting as another (or strictly acting in the absence of another) – a recurring theme in Etzkowitz's work is "each taking the role of the other" (see [42, 172] and Section 2.2.1 for a discussion of the triadic tradition). The creation of the Triple Helix theory was the result of inductive reasoning of successful practices of regional innovation [42], but the model itself derives inspiration from evolutionary economics, sociology, and policy [173]. There are five aspects that create optimal conditions for innovation and these are set out in Table A.15 (developed from [42]).

The model works on two levels: one is to leverage, or forge relationships between business, universities and government for a common cause (demonstrably economic growth see Chapter 4 and Publication 1) but also to change the institutional settings to help deliver the closer relationships (or develop the social capital) that will drive economic growth [171]. This change of institutional settings, or mutual selections can lead to the creation of niches [38] where localised reflexive responses are created (see Table A.16).

Table A.14 Themes of reflexive controls

Author	**Outcome sought**
Leydesdorff [38]	High technology development Global knowledge economy
Etzkowitz [27]	Wealth creation
Etzkowitz and Leydesdorff [20]	New technologies (for example biotechnology and ICT))
Etzkowitz et al [28]	Improving regional or national economic performance
Etzkowitz [39]	Transition to a knowledge-based economy
Etzkowitz [40]	Technological innovation and economic development
Etzkowitz [8]	Science based innovation
Etzkowitz and Zhou [41]	Developing technologies and applied research
Cai and Etzkowitz[171]	Foster regional economic growth and promote entrepreneurship; Research and action

Because each helix is working to its own self-reflexive interest, within a larger overriding framework two further issues arise. One is about the need for clear and effective communication between the helices. If this does not happen, then there is the risk of discord and disruptive evolution [20]. This is an issue that has been recognised by policy makers and why in Europe there is a move to open science, and latterly responsible research and innovation [37] and in Australia responsible innovation [105] (and see Section A.5).

Table A.15 Five aspects of a normative balanced Triple Helix model

Aspect	**Explanation**
Triadic interactions using an Occam's Razor[7] to "remove what is unnecessary" [174] p.145)	The three elements introduce the potential for innovation in innovation with the focus on the reciprocal relations between the three helixes which will be fluid and suffused with (creative) tension.
Take on the role of the other (in terms of adopting new roles)	Institutions doing this differently – for example universities becoming more entrepreneurial and creating new organisations in partnership with other institutions
Evolutionary mechanisms	The model is dynamic with the first two factors creating a non-static space at system and sub-system level (namely market, control and innovation (Leydesdorrf in [42]. The creation of niches further creates dynamic instability and may lead to institutions mutating and changing their genes [42]
Top-down, bottom-up initiatives and lateral coordination	The model is agnostic about where power lies; its strength comes from how power is used. This can be to put in place top-down mechanisms or respond to bottom-up initiatives. This is a development on Cai's [42] argument that government does top down; but in reality, in the Triple Helix any partner can do top down – the key is how the other partners respond
Leadership and capabilities	Triple Helix interactions are enabled by 2 types of conditions – the "sufficient condition of convening authority and the necessary condition of innovation capacity" [42] which links convening authority to individuals who have respect (i.e. social capital) by all partners, but this feels too purist in its approach.

[7] Occam's Razor precludes over-complication unless the complication provides clarity. See Schaffer (2015) for a fuller discussion of the principle and its potential for application in economics.

The point of this work is to deliver economic growth in a manner that society is comfortable with and in so doing helps to transcend the issue of cross-institutional translation [38]. This issue, though not in these terms, has led to the creation of the quadruple helix (see next section)

As discussed in Section A.5, the work on Responsible Innovation is currently strategic in nature and revolves around Triple Helix stakeholders working together to ensure that the next economic wave, or cycle [15] is consistent with, or at least cognisant of, the wider view of society. Currently this work is about the application of technology (for example artificial intelligence [162] or biotechnology [3]) but there is space for these conversations to also evolve into answering questions such as how can we develop partnerships for innovation that deliver a net-zero economy? And this issue will be discussed further in Section A.10 on the Quintuple Helix and in Chapter 6.

Table A.16 Examples of the Triple Helix model being applied (Publication 1)

Author	**Area of study**	**Scale of study**
Cooke [3]	Biotechnology	Regional
Almiral [175]	Social constructs in technology	Local to regional
Hughes [176]	Social living labs	Local
Antonopoulous [177]	Patras Science Park	Regional innovation
Aportela-Rodriguez [79]	Libraries as a link to business	Local
Hladchenko & Pinheiro [178]	Triple Helix in former Soviet Union	National
Artto [108]	Smart Cities and innovation eco-systems	Local
Aslani [179]	Comparative study of Science Parks	Local (but international comparison)
Jongwanich [180]	Triple Helix in China	Regional
Ayvari [75]	Public, private people partnership	Local
Baccarne [90, 128]	Citizen centric urban planning and socio-ecological entrepreneurship	Local
Lukkari [77]	Innovation service platform	City
Bartelt [181]	Public sector and sustainability	City
Berker and Woods [182]	Repurposing university campus	Campus
Boeri [2]	Community development through living lab	Local

The Triple Helix model is a model that is evolving and that is its strength as well as its weakness [35]. The Triple Helix does not, strictly, represent a departure from previous innovation models, but is a development based on inductive reasoning (see [7]) based on evidence from successful innovation practices. It does reflect the increased importance of the university in the triad of relationships, but this is a reflection of the changing economic dynamics rather than model design.

The Triple Helix model is ethno-discursive and has created a considerable body of literature, 17 conferences as well as a research peak body (Triple Helix). It has been used by the OECD, the World Bank and national and regional governments [42]. Because of its evolving nature and fluidity, the Triple Helix model has been criticised as too nebulous to implement. However, Cai [171] has used institutional logics to enhance the context sensitivity of the concept to develop an ideal Triple Helix model based on Western proclivities (see Table A.17).

It is interesting to also reflect that the partners in the triple helix are evolving: universities becoming entrepreneurial (see Section A.1.3) and undertaking contextual [3] or responsible research [105] (see Section A.5); the production of knowledge is moving firmly to a Mode 2, and increasingly Mode 3 transdisciplinary process; in Government the political discourse is about “developing policy as if people matter”[183] delivering the sustainable development goals with the focus on the delivery of policy outcomes that work rather than are ideologically pure; and business is increasingly focussed on open innovation [17] and on stakeholders (see, for example, [16]) as well as the development of a social license to operate ([184].

A.8.2 Criticism of the Triple Helix model

While the Triple Helix model has been widely cited in the literature (for example see [170]) there are questions about its actual impact [35]). There are three consistent strands of criticism of the model

- It is based on a western liberal economic model [33] and pays little attention to national contexts and as such cannot be overlaid onto developed [164] or developing economies without catering for the asymmetric knowledge problem [3] through an elaboration of the context sensitivities [171];

- The model is too general or too strategic [3], lacks a theoretical foundation at the micro (or implementation) level and as such so nebulous as to be more of a think tank than a theory; and [35]
- The model pays insufficient attention to the views of the public or civil society [31] or the natural environment [185].

Irregardless of the critique, the model has promoted a debate in the literature and adopted in wider society about both the knowledge economy and the most effective ways for government, business and academia to work together to create economic growth to benefit society.

Table A.17 Institutional orders in the evolution of the Triple Helix model

Stages of development		**Triple Helix activities**	**Institutional logics**
Stage 1	Realisation of the need	Realising the importance of entering a reciprocal relationship between university, industry and government	Shared beliefs on knowledge as a key to economic growth
Stage 2	Intra organisational transformation	Taking the role of the other	Market oriented organisational culture Process orientated management
Stage 3	Interactions between organisations	Growing and innovating through co-operation Generating hybrid organisations	Effective protection for intellectual property Participate in civil society
Stage 4	Institutionalisation of the Triple Helix model	Feedback loops between participants Institutionalised norms of entrepreneurial university, innovation state, knowledge-based growth	Competitive market environment Democratic policy making process

A.9 Quadruple Helix

In consideration of Mode 3 Knowledge production and the need to embed scientific discourse within a community [21] came the proposed the addition of a fourth helix to the Triple Helix model. The role of the fourth helix is to act as a codification of knowledge within society – it too is a reflexive helix but unlike the other helices it does not exist as an institution or a body that is subject to institutional rules. The fourth helix however plays a theoretically important role and is consistent with the European drive for open science. So here the fourth helix represents media and culture based public relations [21]. But it is more than public relations as it is envisaged that it might result in a 'democracy of knowledge' [21].

The fourth helix represents the importance of public, or deployment of social capital for the "successful achieving of goals and objectives" [21] p218. Whilst it is not clear who 'owns' the goals and objectives and the public are influenced by culture and values, but so too are industry, government and academia.

This is the importance of social capital [29] to the debate. What is not clear is why the public's social capital is differently applied or will result in different reflexive positioning than the other helices. The key to answering this question is the appreciation that the Quadruple Helix is the media-based reality construction [31] and represents the social structure that underpins the Triple Helix.

The addition of a fourth helix does bring with it a discussion of the democratisation of knowledge production and innovation systems [36]. What is less clear is why this democratisation of knowledge is not catered for in the government helix (particularly in a Western industrial democracy)? In a sense this is answered by von Hippel [16] who argues that users (both business and individuals) have increased power through the democratisation of innovation (using knowledge) and are able to innovate for themselves (this links back to Drucker and individuals, and organisations innovating). Carayannis et al [185] argue that the Quadruple Helix has the user at its core which is where the strength of the Quadruple Helix lies.

A.10 Quintuple Helix

The Quintuple Helix adds a further helix to the Quadruple Helix. The fifth helix is the environment or natural environments. In so doing it is argued the Quintuple Helix offers an analytical framework where knowledge and innovation are being connected with the environment or natural environments [21]. The development of the Quintuple helix is consistent with the transition to Mode 3 knowledge production and sets an ecological boundary around the conceptualisation of knowledge production and innovation. This is defined as a co-opetitive spatial and sectoral fractal innovation and entrepreneurial ecosystem (CS2FIE2 [185]). The emphasis is on the innovation process as an ecosystem whereas under the Quadruple Helix model it is referred to as an innovation system [185].

Under this model two definitions of sustainable development are offered. One is the Brundtland definition of "development that meets the needs of the current generation without compromising the ability of future generations to meet their own needs" [144]. Carayannis et al [185] however, introduce a further definition of sustainable development as "a co-evolution of the different systems of society, based on knowledge and a mutual cross-learning that is socially and environmentally sensitive and that is receptive for concepts of a quality of democracy and demonstrate the usefulness of social ecology and the potential for a socio-metabolic transition where material and energy flows are in equilibrium for the benefit of society and nature".

The natural environment(s) of the fifth helix is not a helix nor is it presented methodologically as a boundary within which the innovation processes take place. It is stylised as carrying out the quasi function of a helix as it promotes innovation and under the Quintuple Helix all systems influence each other [32]. The promotion of sustainable innovation is the useful contribution of the quintuple helix. Although criticised for being anthropomorphic (see [42] and next section) the usefulness of the fifth boundary helix is to transposition the discussion from "what society cannot do" due to a planetary boundary to one where the emphasis on "what can society do" but within this model *without* planetary constraint. Irregardless, this is useful as it is the classic representation of the economic problem of unlimited wants constrained by limited resources (see for example [186]). Bringing together

knowledge creation, innovation systems and the environment explicitly within that context is helpful.

There is a 5-step flow analysis to help understand the practical implementation of the Quintuple Helix [32]. The example starts with an investment in *education* and the process is then explained in Table A.18.

A.10.1 Criticism of the Quintuple Helix

Cai and Etzkowitz [42] describe the addition of natural environments of the society as the fifth helix as "introducing and anthropomorphic fallacy into the model" (p9). They do not however explain the fallacy, although the language chosen by Carayannis [32] does suggest an unnecessary and uncharacteristically loose anthropomorphic sentiment (for example see Step 3 in Table A.18). However, the principle of including representation of a finite constraint (however nebulous) that reflects the reality confronting society (see [97] [187]) is useful. Within this model that constraint, however, is negated by its inclusion as another sub-system rather than as a system boundary.

The key, but unstated in the literature, weakness of the Quintuple Helix model is a return to a more linear approach to innovation, where innovation becomes more of a process than an evolution, with insufficient explanation as to why wealth (being the creation of various forms of capital) will be more sustainable under this model than the Triple Helix or any other model. Further the use of various sobriquets to describe what the fifth helix is presented to achieve is unhelpful (see A19 for definitional issues).

As there is no planetary boundary within the Quintuple Helix the issue of finite resources does not interact with decision making and does not offer an explanation as to why a Quintuple Helix model, though with the addition of a fifth helix, will be any more sustainable then the Triple or Quadruple Helix.

Table A.18 The 5-step flow analysis of Innovation under a Quintuple Helix model

Step	Innovation sub-system	Description
1	Education	Inflow of investment into education which creates new impulses and suggestions for knowledge creation, which in turn increases research output in sustainable development. Due to the increase in human capital this output becomes an input into the economic system.
2	Economy	The input into the economic helix increases the value of the knowledge economy through the creation of new jobs etc. In this economic sub-system demand for corporate social responsibility and a sustainable future is increased.
3	Natural Environment(s)	The economic output "communicates with nature that it will be increasingly protected" (p8). The output of this sub-system is to provide more environmental protection and a better quality of life for people. According to Barth [188] the economic capital of know how in this context is sustainability.
4	Media-based and culture-based public	The public receive information capital about how to live a greener lifestyle and the new knowledge created should be implemented by the newly created social capital in the social-based public. The output of this system is information on "wishes, needs, problems or satisfaction of citizens into the political system
5	Political system	The input from the culture-based public (and other sub-systems creates new political and legal capital that makes the likelihood of living in a less unsustainable world achievable. The output from the political system then feeds the other subsystems.

According to Cai [42] a further weakness is that the triadic tradition is lost. The triadic tradition removed the linearity from the national innovation system and introduced an unconstrained evolutionary approach. The triadic tradition (*entwicklung*) is powerful. At its core it proposes that philosophy will not contradict experience but rather experience will contribute to philosophy to reveal the true explanation. Triadic represents three but should not be misconstrued as the three helices. The three elements of the triadic tradition are more about process than institutions. The three parts are: in itself; out of itself and finally in and for itself. The triadic tradition is powerful as it focuses on what might become as well as what is [189].

Studies of the quintuple helix are currently limited and led by Carayannis [32, 185]. Baccarne [128] has taken the concept and applied it to an urban living lab concluding that the urban living lab approach is a way to put the model into practice at the level of a single localised innovation development process. It has also been applied, using fuzzy logic to the *ex-ante* implementation of the sustainable development goals in Latin America [33], rather than the decision making that led to the implementation.

A.11 Triple, Quadruple and Quintuple models: Summary

The Quintuple Helix model is a conceptually useful development as it provides a conceptual extension of the modes of knowledge creation and the systems of how the knowledge is used to innovate. Conceptually the Quintuple model also provides an envelope within which innovation needs to take place. It is also non-judgemental about the weighting between the helixes [33]. Providing this structure does mean that it reconceptualises economic opportunity and the opportunity for knowledge creation and innovation (see [185]. It starts to answer the questions posed by Boulding [97] but does not yet provide the answer to Hardin's [91] search for a technical answer to the tragedy of the commons.

A.11.1 Partnerships for innovation – the creation of hybrid organisations

As discussed in Section A.8 the Triple Helix model gives rise to the potential for new hybrid organisations due to the interaction between the helices [27]. The deepening of the knowledge-based economy is affecting how all partners interact – government, industry and universities but also how consumers and citizens interact with other partners in the innovation ecosystem [43]. As discussed in Section A.9 the inclusion of the local citizen has led to the conceptualisation of a Quadruple Helix model [31]. But the rate of pace of change, partly driven by the new power dynamics offered through the democratisation of knowledge [21] is giving rise to new forms of individualised partnerships [44] at different scales and different dynamics [46]. This result is as predicted by Etzkowitz [27] in his proposal of the Triple Helix model. In ecological vernacular these would be referred to as niches that are created through some form of mutual serendipity to meet a localised need [38].

Much of the literature (see Table A.19) refers to these hybrid organisations, or intermediaries for innovation as resulting from a top-down or bottom-up initiative. There

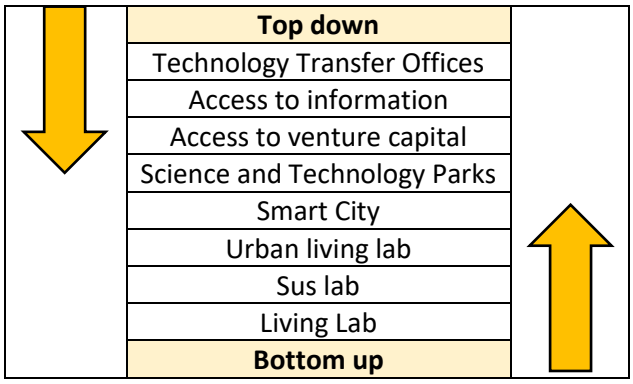
are no dissenting voices in the literature to adopting this approach to suggest that it is theoretically invalid (see Section 4.1.2). But the findings of the systematic literature review undertaken as part of the research suggests a further refinement to this paradigm that takes into account the increasingly important role of society in its many forms in developing innovation (Publication 1 [12]). The evidence underpinning the new model has been discussed in Section A.5 on Responsible Research and Innovation which has resulted from the international push towards open science [37], the development in business of a social license to operate [184]; knowledge production moving from Mode 2 to Mode 3 and the take up of open innovation [17] and policy being created "as if people matter" [183].

Table A.19 Definition of helices in Triple, Quadruple and Quintuple models

Model	**Authors**	**Definition of helices**	**Summary of focus**
Triple Helix	Etzkowitz and Leydesdorff [27]	Universities, industry government relations	Knowledge economy
Quadruple Helix	Carayannis and Campbell [21]	Media-based and culture-based public Civil Society [185] Citizens ([190] Public environment [33]	Knowledge society
Quintruple Helix	Carayannis and Campbell [32]	Environment Natural environment(s) Social ecology Social, or societal, ecosystem Natural environment(s) of society Ecological Capital (Barcellos-Paula 2021)	Socio-ecological transition

This empowerment of people needs to be recognised and this has led to the evolution of the proposed three streams of partnership development which is a revisualisation of the extant top-down/bottom-up approach (see Table A.20) currently endemic in the literature. Both the existing top-down/bottom-up analysis and the three-stream approach are based on the premise that it is through the development of situationally specific partnerships at different scales and under different dynamics that best facilitates the likelihood of innovation happening (the innovation equivalence of Darwinism). This is discussed in full in Section 6.2.

Table A.20 Extant top down/bottom-up approaches to partnerships for innovation



A.11.2 Concluding remarks

This literature review complements the systematic literature review published for this thesis (Publication 1). Building on the top-down/bottom-up paradigm [34] in the published literature it is demonstrated that partnerships for innovation are the result of progressive changes in knowledge production and are also a result of the democratisation of knowledge and the emergence of society as an important partner in innovation. These external stimuli to the ecosystem of knowledge production and partnerships for innovation have then created their own structures that reflect the changing external stimulus.

This literature review also demonstrates that there has been an evolution in thinking about knowledge production and innovation processes. The pre-eminent model in the literature (and widely adopted in society) is the Triple Helix [27]. This then was developed into a Quadruple Helix (to consider media-based and society-based public participation) [21]. This in turn was developed into the Quintuple Helix to consider sustainable development [32]. This literature review, and the associated systematic literature review (Publication 1 [12]) has introduced the concepts of exogenous stimuli that has necessitated a development in the theoretical models.

However, the literature review has also revealed that the model development (as set out in Table 7.7) suffers from theoretical weaknesses that mitigate its usefulness. These are discussed further in Chapter 4.

Appendix B Publications

B.1 Publication 1

Burbridge, M. & G. Morrison (2021) A systematic literature review of partnership development at the university-industry-government nexus. Sustainability 13, no. 24: 13780. https://doi.org/10.3390/su132413780

sustainability

MDPI

Review

A Systematic Literature Review of Partnership Development at the University–Industry–Government Nexus

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Abstract: The increasingly entrepreneurial intent of universities implies the commercialization of knowledge and innovation through the triple helix of interactions between universities, industry and government. However, there remains a lack of clarity concerning best practice partnerships for innovation. This systematic literature review (SLR) provides insights onto the development of partnerships at the university–industry–government nexus and builds on the existing top-down/bottom-up approach for the creation of intermediaries of innovation. The SLR describes the evolution of these intermediaries, which is driven both by criteria set by partners and the globalization of the knowledge economy. This SLR reveals that the partnership structure most likely to further economic and broader societal goals is the living lab with the inherent focus on open innovation and co-creation. This SLR reveals that the living lab structure (and including sustainability labs and urban living labs) is the partnership structure utilized for innovation that addresses economic, social and environmental goals. Two areas are recommended for further research. One concerns the development of a deeper understanding of the relationship between the evolution in the structures of partnerships for innovation and how it is influenced by the globalization of the economy, society and environment, and changing modes of knowledge production. The other is to better understand why the living lab approach to partnership creation is best suited to the delivery of sustainable development objectives and how this learning can be applied to other models of partnership development at the university–industry–government nexus.

Keywords: triple helix; innovation; partnership development; sustainable development

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1. Introduction

Since the 1940s, there has been a push to encourage universities and industry to increase their engagement to commercialize research [1]. This started with the use of government procurement to encourage research and the development of innovative products [2] initially in the space, defense and energy sectors [3]. The 1950s and 1960s saw the development of science and/or technology parks to commercialize research [4] in America, which was followed, during the 1980s, in the UK [5].

During the 1980s, universities developed an increasing focus on technology transfer [6] to facilitate engagement with business. However, it was only from the 1990s that universities became directly involved in the world of business, actively seeking to commercialize their knowledge and research [3].

The benefits of collaboration range from the local (commercialization of research and innovation [7]) to the regional (revitalization of regions [8,9]) or national (catalyst for techno-economic development [10]) levels. Collaboration is a key part of modern innovation [11], which in turn is an important part of a well-developed entrepreneurial industrial sector [12].

The triple helix model [13] highlights the importance of a partnership between universities, industry and government to create innovation that meets business objectives in

developing and commercializing universities' research outcomes. Including government within the partnership creates outcomes that are socially and economically beneficial [14,15]. Others [16] have proposed the addition of a fourth helix (the quadruple helix) to promote a democratic approach to innovation, where society can provide feedback to create socially acceptable policies and practices. However, this model does not include the explicit consideration of non-market parameters, such as the natural environment [17]. The quintuple helix [18] seeks to address this shortcoming.

However, universities, industry and government struggle to effectively partner—particularly at scale—to deliver economic benefits from the commercialization of research outputs [19–21].

The aim of this systematic literature review (SLR) is to identify best practice partnership development to promote innovation at the university–industry–government nexus. To do this, it seeks to understand how universities partner with external organizations to deliver innovation and tracks the development of these partnerships.

This article is structured as follows. Section 2 sets out the methods used in the SLR; Section 3 provides a quantitative analysis of the papers revealed through the SLR; Section 4 discusses these results and puts forward a new understanding of the development of partnerships for innovation at the university–industry–government nexus; and Section 5 proposes a further research agenda.

2. Methods

The SLR offers a stringent methodology to interrogate a large body of data in a manner that is repeatable and evidence based [22]. This removes much of the inherent bias that can befall more traditional literature reviews [23]. However, using repeatable search terms does not in itself remove the potential for author bias [23]. The SLR provides a stringent approach, where the selection of studies is repeatable, but where the interpretation of those studies is left to the authors [24]. In order to develop a repeatable process for the interpretation of results, this study applies a thematic analysis approach developed by Massey (2011), which was initially proposed for use in interpreting the results of focus groups [25]. Massey's [25] process is applied here to further manage author bias by highlighting the epistemological foundation for the work.

This SLR is consistent with PRISMA (preferred reporting items for systematic reviews and meta-analysis) [26] and follows the process set out in Figure 1.

The articles were analyzed using Massey's model for thematic analysis [25]. This approach increases the replicability of the study, as it proposes three levels for data analysis: articulated, attributional and emergent [25]. Categorizing data into these three levels enables a transparent analysis which is repeatable and develops an analysis that is descriptive and based on a systematic approach.

However, Massey's (2011) model is not immediately transferable, as it was designed to be used for analyzing data arising from focus groups rather than from SLRs. Massey's three definitions of each data level are included in Table 1. The three levels of data should be viewed as a hierarchy, where the potential for bias is inverted according to its position in the hierarchy, with articulated data being subject to the least bias (and therefore, most replicable), whereas attributional and emergent data are the least transparent, due to the necessary engagement with the authors' views and experiences in the SLR process.

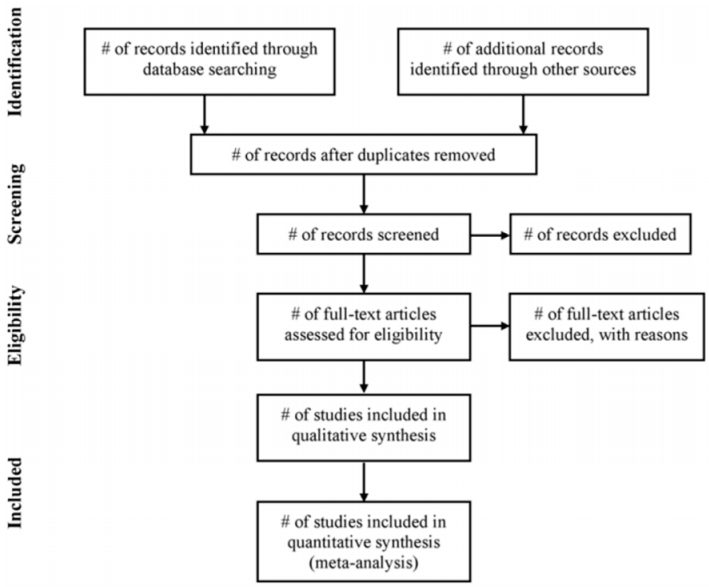

Figure 1. PRISMA—flow of information through the different phases of a systematic review [26]. The number of results is shown in Tables 2–8. # = number.

Table 1. Model for thematic analysis of data—based on [25].

Levels of Data	Original Definition	Revised Definition	Source of Data	Potential for Bias
Articulated data	Information that is expressed in response to, or specifically addresses the questions posed	Information that is stated directly by the original research authors as the result of their research. This is the original author's statement of results achieved and reported in the articled	Data are articulated by one or more study in the SLR	Lowest
Attributional data	Comments and discussion that relate to a priori hypotheses or theories that the evaluator brings to the study	Unchanged	Data are a co-location of ideas from 2 or more articles and are supported by extant models and theories	Medium
Emergent data	Information that contributes to new insights and hypothesis formulation and is the unanticipated product of individual comments and exchanges amongst group members.	Information that contributes to new insights and hypothesis formulation and is the unanticipated product of connections arising from different articles	Data that are the result of the consideration of articulated and attributional data. They are not necessarily supported by an extant body of work	Highest

2.1. Research Question

The aim of this SLR is to identify best practice partnership development to promote innovation in the university–industry–government nexus. To do this, it seeks to understand how universities partner with external organizations to deliver innovation. Further, it investigates the question of how innovation can be undertaken in a manner that is consistent with sustainable development.

2.2. Identification of Relevant Studies

Having defined the research question, it was then necessary to construct a search string for use in 3 key databases (ProQuest, Scopus and Web of Science). Defining the search terms was an iterative process, but the Boolean search was designed to reveal the state of the literature regarding how universities partner with business (and government) to transfer or develop knowledge to create and/or commercialize innovation.

The search was initially narrowed to include sustainability, carbon, sustainable development (and variants) in order to consider the appropriateness of the research or innovation to move society toward delivery of the sustainable development goals [27] but adding these elements to the search string returned too few articles from the search. A new search focusing on sustainable development and partnerships for innovation at the university–industry–government nexus was undertaken, which revealed a further 7 articles.

The development of the search string was determined from the problem definition and then combined into a Boolean research string (as set out in Table 2). Where the option was given, databases were searched for peer-reviewed articles written in English. There was no temporal constraint imposed.

Table 2. Development of Boolean search string.

Key Areas	String Expression
Activity	Innovati * or research
Location of activity	"campus develop *" OR "living lab *" OR "sus * lab *" OR "tech * park" OR "science park" OR "innovat * park"
Form of activity	collaboration OR "co-creat *" OR partner * OR "triple helix"
Between	university OR academi* OR college AND industry OR business OR commerce

* = root, stem or truncation.

2.3. Process of Filtering Studies in the Systematic Literature Review

The process of filtering studies in this SLR follows the PRISMA phases of a systematic review [26,28], with additional data considered relevant to the quantitative elements of the SLR retained.

2.3.1. Records Identified through Database Searching

The research string was run through all three databases in December 2020. The results for each database are shown in Table 3.

Table 3. Records identified through database searching.

Database	Boolean Search Results
Proquest	168
Scopus	151
Web of Science	171

2.3.2. Records Removed

Once the search of Scopus, Proquest and Web of Science was undertaken, the first step was to remove any duplicates within each database. Opinion articles and articles not in English were also removed from each database. The result of this process is shown in Table 4.

Table 4. Removal of duplicates, editorials and non-English papers.

Database	Search Results	Number Removed	Number Remaining
Proquest	168	14	154
Scopus	151	4	147
Web of Science	171	5	165

Having removed internal duplicates, editorials and non-English papers, all articles were reviewed to ensure that they were consistent with the objectives of the SLR. This process involved reviewing the titles and key words of the papers to make sure that the area of study was consistent with the research question. The results for this process are set out in Table 5.

Table 5. Removal of non-relevant papers (by title).

Database	Number of Papers	Number Removed	Number Remaining
Proquest	154	27	127
Scopus	147	2	145
Web of Science	165	35	130

Databases were amalgamated, and duplicates between databases were removed. The results can be seen in Table 6.

Table 6. Removal of duplicates between databases.

Database	Number of Papers	Number Removed	Number Remaining
Combined	402	65	337

2.3.3. Number of Records Screened (and Records Removed)

All abstracts were read to ensure that papers were relevant to the research question. Papers had to address innovation or research between two partners, either at some location or by addressing the issue of the location of the research or innovation activity. Papers that were not consistent with the research objectives of the SLR were removed. See Table 7.

Table 7. Removal of non-relevant papers (by abstract).

Database	Number of Papers	Number Removed	Number Remaining
Combined	337	154	183

2.3.4. Full Text Articles Assessed for Eligibility (Full Text Articles Excluded)

All papers that could be accessed were downloaded. Papers were then read and coded. Papers that were not consistent with the research criteria were at this stage eliminated. See Table 8.

Table 8. Final papers for data synthesis.

Database	Number of Papers	Number Removed	Number Remaining
Combined	183	51	132

2.3.5. Number of Studies Included in the Qualitative Synthesis and Meta-Analysis

The number of papers remaining in this study after the filtering was 132. These were then analyzed quantitatively (Section 3) and qualitatively (Section 4).

3. Results

The data were synthesized through two stages. Firstly, they were analyzed according to the factors detailed in Table 9. This part of the analysis dealt with issues such as publication date, type of study, location of where research/innovation took place, and location of the lead author.

Table 9. Data synthesis—data categorization (based on Eon and Morrison in print).

	Criteria	Description
1	Year of publication	Year that the article was published
2	Country of lead author affiliation	Location of lead author affiliation
3	Type of publication	Publications were differentiated into: Journal Book chapter Conference paper
4	Type of article	Articles were divided into three broad categories: Case studies (where performance of research and innovation at a specific location or locations were described and detailed). Review papers where performance of a series of partnerships were assessed and conclusions drawn about efficacy or partnership models, future policy or research direction. This includes literature reviews Model development identifying different means of assessing the performance of research and innovation partnerships.
5	Country where case study research took place	Location of where the case study took place
6	Physical location of where the innovation took place	Detailing the focus of the research on the physical space. Spaces (or places) were categorized: Nation state Regional (including rural and peripheral areas) City Science and Technology Park Campus Living lab

The second phase (see Section 4) was the synthesis of the data. Data were coded and synthesized into the three categories set out in Section 2.

3.1. Data Synthesis

All papers were categorized according to the criteria set out in Table 9. This categorization was undertaken to establish the year of publication, the location of the lead author, the type of publication and article, and the physical location of the innovation partnership. These data are largely factual, although there is an element of subjective interpretation in the categorization of papers.

3.1.1. Temporal Distribution of Studies

Of the 132 papers included in this study, 106 were published in the past 10 years. The trend in publishing is increasing and the interest in partnerships for innovation is similarly increasing (see Figure 2). This trend has been observed by others (for example [29,30]). A discussion for the drivers of the increased interests in partnerships for innovation, rather than the evidence of the increase in interest, is beyond the scope of this SLR. The

figures for 2020 represent data for 11 months (as the primary searches were conducted in December 2020).

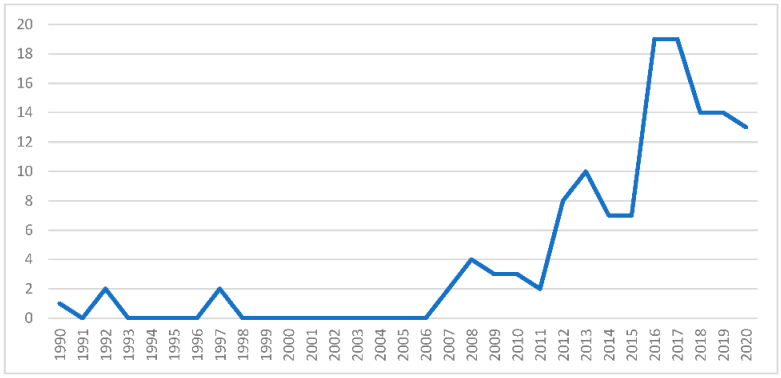

Figure 2. Temporal distribution of studies.

3.1.2. Country of Lead Author Affiliation

The country of the lead author affiliation is set out in Figure 3. The top 5 European countries published 69 studies or 52% of all the studies in the SLR. European authors published 78% of the papers identified in this SLR.

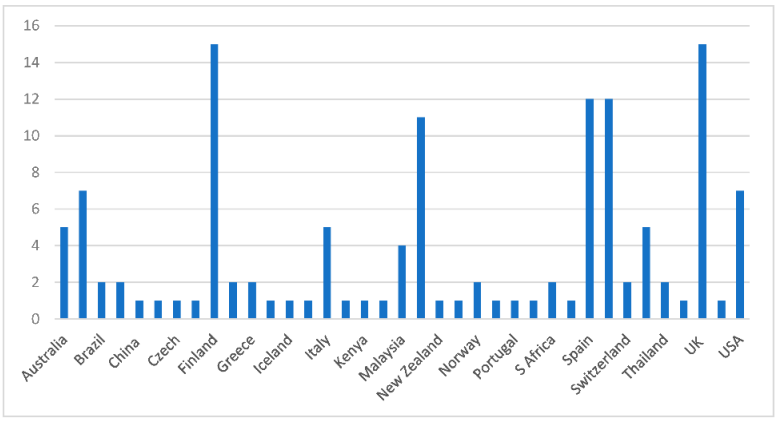

Figure 3. Lead author—country of affiliation.

A breakdown of lead author affiliation by continent is given in Table 10. This reinforces the dominance of Europe for research into partnerships for innovation. The dominance of Europe in the research field is not surprising, given that the co-creation of innovation was a priority of the Finnish Presidency of the European Council in 2006 [31].

Table 10. Lead author—affiliation by continent.

Continent	Number of Papers
Europe	97
Asia	13
N. America	9
Australia/Oceania	6
Africa	5
S. America	2

3.1.3. Type of Publication

Table 11 illustrates the breakdown of the sources for the articles used in this SLR: 85% were journal articles, with 4% being from conference papers.

Table 11. Type of publication.

Type of Publication	Number of Papers
Journal article	112
Book chapter	14
Conference paper	6

3.1.4. Type of Article

This SLR considered 132 articles. The type of article is set out in Table 12. For this analysis, we used only three broad categories of articles, as drawing the boundaries is difficult and ultimately adds little to the sum of knowledge. The principle of Occam's razor was applied [30].

Table 12. Type of article.

Type of Article	Number of Papers
Case study	103
Review	24
Model development	5

A case study was deemed to be a study looking at a specific partnership that was used for research and/or innovation (these could be site specific, region specific, sector specific, or process specific). A review was defined as a study that considered the performance of a range of case studies to develop a future research agenda, present that state of the field, or make proposals for future policy. Finally, model development was defined as the development of evidence for proposals of new performance matrices or new forms of partnerships. Undertaking even such a simplified classification process requires the application of expertise and is, therefore, subjective.

3.1.5. Case Study—Location and Focus

An analysis was undertaken of the physical and geographic location of the 104 case studies in this SLR. The physical location was defined as the place, or predominant place, where the partnership for innovation took place. Table 13 demonstrates the physical (rather than geographic) location of all 103 case studies reviewed by this SLR.

Table 13. Focus area of case studies.

Focus Area of Case Study	Number of Papers
Science and Technology Park	28
Campus	21
Living Lab	21
City	14
Regions	11
National	6
Business	2

3.1.6. Single Country Case Studies

There were 87 single case studies in this SLR, with the remaining being trans-border or trans-continent. This demonstrates the importance of Europe to research into partnerships for innovation. Figure 4 details the geographic location of the single case studies.

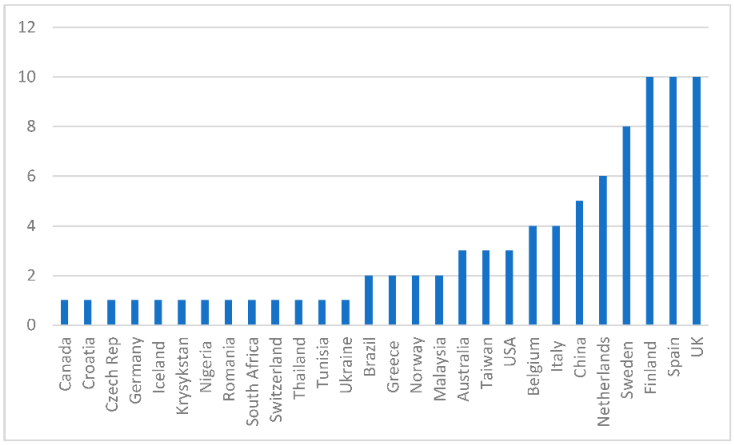

Figure 4. Country of single case study.

3.1.7. Case Studies in More Than One Country

There were 18 studies that were trans-border case studies; details are set out in Table 14.

Table 14. Trans-border case studies.

Trans-Border	Countries	Number of Case Studies	Authors
International	The Netherlands, USA.	1	Curvelo Magdaniel, De Jonge [32]
	Spain, S. Africa, Hungary, Czech Republic, Finland	1	Schaffers, Cordoba [33]
	USA., Greece, Portugal	1	Schoonmaker and Carayannis [34]
	Finland, South Africa, Spain, Sweden	3	Leminen, Westerlund [35] Leminen [36] Leminen, Nyström [37]
	Spain, Hungary, South Africa	1	Guzman, Schaffers [15]

Table 14. *Cont.*

Trans-Border	Countries	Number of Case Studies	Authors
International	Spain, Mexico	1	Olvera, Piqué [4]
	USA, Iran	1	Aslani, Eftekhari [38]
	USA, UK, Bulgaria	1	Purcell, Henriksen [39]
Intra-European	Sweden, Finland	1	Buhr, Federley [40]
	Denmark, Norway	1	Nielsen [41]
	Finland, Belgium	1	Veeckman, Schuurman [42]
	Portugal, UK	2	Martins [43] Germain-Alamartine and Moghadam-Saman [44]
	The Netherlands, Sweden, Finland	1	Voytenko, McCormick [45]
	Finland, Spain	1	Almirall, Lee [46]
Asia	South Korea, Taiwan	1	Yun and Lee [47]

4. Discussion and Analysis of the Data

The data in this SLR were analyzed using a systematic process and the results are discussed below. Section 4.1 sets out the articulated data—these are data that are revealed by one or more study. The evolution of a non-hierarchical structure emerged to assist with understanding the development of partnerships for innovation at the university–industry–government nexus. Section 4.2 presents the epistemological backdrop to the articles to present a more nuanced understanding of the articulated data. Section 4.3 presents emergent data, which are author insights developed through engagement with the articulated and attributional data.

4.1. Articulated Data

This section presents the thematic results of the data analysis as revealed by the SLR. The aim of this SLR is to reveal best practice partnership development to promote innovation in the university–industry–government nexus. To do this, it seeks to understand how and why universities partner with external organizations to deliver innovation.

This section is divided as follows. Firstly, there is a reprise of the theory of partnership development at the university–industry–government nexus (Section 4.1.1). Following this is a discussion of the intermediaries for innovation created at the university–industry–government nexus and how they are currently portrayed in the literature (Section 4.1.2). Finally, an evolutionary view of the creation of intermediaries for innovation is proposed (Section 4.1.3) that describes the development of partnerships for innovation. These are based not solely on dynamics within the partnerships, but on external factors that have facilitated, or enabled, new forms of intermediaries for innovation (Section 4.1.3 present the evolution of the three forms of partnership revealed in this SLR at the university–industry–government nexus).

4.1.1. Innovation at the University–Industry–Government Nexus

Economies have become increasingly dependent on the exploitation of knowledge for continued economic growth [1,4] and the role of the university is widely debated [48–51]. Universities play a key role in furthering future economic development, due to their missions to educate, carry out research and engage [52,53]. It is the third mission (engagement) that gets the most attention in terms of how universities can most effectively use the knowledge they create to further economic development [54,55] and do so in a manner that is in the economic interest of society [56,57]. To efficiently utilize their expertise in knowledge creation for the economic benefit of society, there is a need to interact, or partner,

with other organizations [34]. There is limited discussion about how universities themselves might use innovation to improve their offerings under missions one and two (see, for example [58,59]).

There is an ongoing conversation about the triple helix, where universities, government and industry interact to help drive knowledge-based economic development, particularly in an industrialized economy [51,60]. Academic interest in partnerships for innovation is increasing as reflected in Section 3.1.1. The triple helix model is largely accepted as a useful starting point to understand the changing roles of universities, industry and government to partner in innovation to drive economic development.

4.1.2. Intermediaries for Innovation at the University–Industry–Government Nexus

The SLR reveals that the innovation intermediaries created by university, industry and government are created through an internal dynamic, and these are either management led (top-down) or led by an entrepreneurial individual or group (bottom-up) [54,60]. These types of intermediaries for innovation, as identified in the literature, are shown in Figure 5.

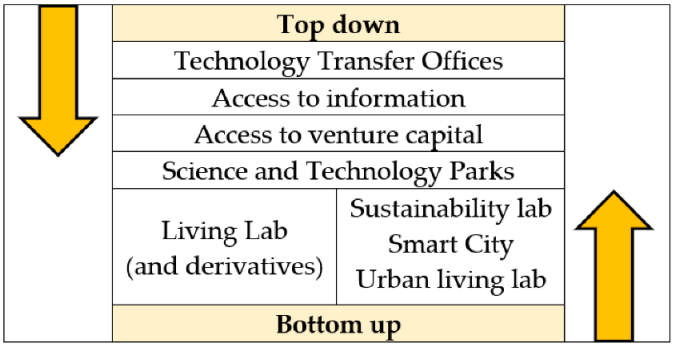

Figure 5. Innovation intermediaries in our society [54,60].

Whilst there is a focus on economic development, it is clear from the literature that the deepening knowledge-based economy is affecting not only how industry, government and universities interact, but also how consumers and citizens [34] interact with other partners in the innovation ecosystem. The pace of change affects all sectors of society (university, industry, government as well as people), and this dynamic relationship is rapidly changing, which is leading to new forms of intermediaries that are highly individualized [61]. This, in turn, leads to the opportunity for innovation at different scales and under differing dynamics and delivering different outcomes [62,63].

Various forms of intermediaries are being created as a result of internal dynamics, but also being facilitated by external opportunities and stimuli (exogenous factors). It is this overlay of changing dynamics that has led to new forms of intermediaries for emerging innovation [64] and that are being led by, or include, different actors [65] or different power dynamics and approaches [62,66]. Additionally, new models for innovation are being adopted by different sectors—including the public sector [67] or cities [68]. It is this change in dynamics, structure and power relationships that is leading to the nascent creation of innovation that is seeking to deliver economic, social and environmental enhancements at the same time [19].

4.1.3. Evolution of Intermediaries for Innovation

This SLR reveals an evolution in the ecosystem of intermediaries for innovation. Intermediaries for innovation are individuals or organizations whose role it is to span the boundaries between organizations to facilitate innovation [69]. Innovation intermediaries

are evolving from a simple partnership model of a technology transfer officer, through to the development of science and technology parks (STPs) and through to living labs and smart cities. This is a non-linear pathway [60], partly due to the rapid change in the nature of the knowledge-based economy—where knowledge is increasingly shared rather than owned [67], partly as a reflection of a change in knowledge production [16] and partly due to an increased focus (particularly in industrial economies) on the importance of the service-based economy, where service (experiential or simply more tailored [46]) is seen as another key to unlock economic development.

- On Campus Structures

On-campus structures includes the creation of several organizational structures within universities to promote the development of partnerships for innovation. These forms of partnership are the simplest and are an organizational response to facilitate the creation of an increasingly entrepreneurial university [60]. In the initial phases at least, this is conducted on campus.

The structures put in place range from technology transfer offices [69], academic liaison officers [56] to act as an intermediary between the university and business, processes to facilitate access to library information for business [52] and the creation of incubators to help start-ups grow into functioning businesses [70]. The purpose of these mechanisms is to assist the transfer of knowledge from the researcher to the consumer via a business.

There is also some evidence in this SLR of the campus itself being used as an innovation, and these were underpinned by a planning perspective [71], asset management [72], by opening up the campus [73] or using the campus to drive radical innovation through institutionalization [74]. These studies show the potential for the entrepreneurial university to drive all three modes (education, research and commercialization) through the operation or development of the campus.

- Development of Campus-Adjacent Structures

The second significant phase in the development of intermediaries for innovation is the creation of campus-adjacent structures to further the partnership between universities and business. In this SLR, there were 28 case studies looking at STPs (see Section 3.1.5). The impetus for the creation of these off-site structures seems to be university, or government driven, but there are examples of it being driven by the private real estate sector [32]. In this SLR, most papers considering STPs focused on a traditional form of STP, where a university creates spaces for businesses to occupy to deliver innovative goods and services (ideally based on or related to the intellectual output of the university).

These campus-adjacent structures have a complex nomenclature, but in this SLR, they are referred to as science and technology parks (STP). This is a generic term to take in research parks, technology parks, innovation parks and business parks. The key definition issue is that they are developed to create an environment conducive to the co-creation of economic value by business, ideally using university created knowledge. They are geographically proximate to the university and tend to focus on the research strengths of the university.

The value of geographical proximity is much debated [75]. This SLR showed strong informal connections between universities and business [52,76–78] based on geography but with less evidence of formal connections that deliver innovation based on university-created knowledge [75,79]. One study found that 92% of the on-park research and technology output was through private industry [80], with others considering the role of private capital to innovation success [50], the role of university finance to spin-off success [81] or the role of management [82], or the network benefit [83]. This does not, in itself, mean that STPs represent a failed policy, but that there is not strong evidence for the successful transference of knowledge from creator to consumer via a business based in the university's STP. The depth of these relationships depends upon the level of service offered by the university to its tenants—with non-core assistance (for example, human resource management functions) being valued by tenants [77] or the value of social capital to start-up success [49].

There is also a stream of work researching the connection between the university and the STP covering the role of knowledge transfer facilitated by librarians [56], the influence of the university on the STP [84], the impact of doctoral education [44] or a more holistic consideration of the STP compared to a technology transfer officer or other intermediaries (see Section 4.1.3) [69].

Although the usefulness of STPs is still subject to debate, the creation of STPs has been adopted in Europe [7,9,41,70,79,80,85–88] and North America [1], and STPs are widely emulated in the former Eastern bloc countries [11,89,90], as well as the centralized economies of China [2,55,91], Taiwan [92,93], Malaysia [53] and others in Asia; the creation of STPs is also seen as a pathway for economic development in developing nations [8,94–96] as well as being subject to international comparisons [4,34,38,47].

- Development of Living Labs

The next phase in the evolution of intermediaries for innovation is the creation of living labs. As shown in Section 3.1.5, there is a significant body of work which investigates the role of living labs. These are partnership structures that are focused on user engagement and open innovation. The partners are varied but generally involve university, business, and government (at some level). Living labs (and derivatives) are driven by a desire to innovate within the partnership and this might be the deepening of research findings [97], creating a product or service to commercialize the research [98] or co-creating a new product or service [99].

The external change that is facilitating the development of living labs is the ability for a range of stakeholders to become freely involved in the process of innovation [100]. The service-dominant logic [48], open innovation [101], user innovation [29], user-centered design [102] or even social (rather than economic) innovation [103] have become possible due to the ability to create communities of interest for almost anyone.

Living labs (and derivatives) are widely debated in the literature and are normally considered a network that incorporates both user engagement and open innovation [35]; they have the characteristics as set out in Table 15. There are several forms of living labs, which are also evolving. Sustainability labs [104] are focused on the delivery of economic, social and environmental outcomes at a geographic location. Smart cities are developed as a higher systems level solution under which living labs enable the demonstration and prototyping of products and services. Urban living labs are a network structure within an urban environment [64].

Table 15. Living lab characteristics [29].

Characteristic	Explanation
Real life environments	Real life experimentation to test, develop, research new products, services, systems, processes
Stakeholders	Range of partner involvement to co-create. Stakeholders are key to the outputs of the living lab
Activities	What the living lab will focus upon. This is defined by whoever is driving the innovation (and is key to delivery of the output/outcome)
Business models	Covers how the living lab will operate (essentially why it exists and how it will continue to exist)
Methods and tools	The approach taken to innovation
Challenges	Economic, social and/or environmental
Output and/or outcomes	What the living lab delivers
Sustainability	Emergence of innovation that moves society toward delivery of the sustainable development goals

However, both the literature and practitioners struggle to define living labs and their derivatives [29,64], or to create business cases to build them [65,104], or even best practice guides to help manage them [31]. They are a rapidly evolving creation that, in many respects, is a direct expression of the partnership that created them [104]. That said, there are structures to suit different desired outcomes, such as wicked issues [105] or radical innovation [74], and they are grouped into a genus containing 4 typologies characterized by open innovation: utilizer driven, enabler driven, provider driven, and user driven [35].

At the heart of living labs are two key elements: user engagement and open innovation [35]. These two aspects are evident in the case studies in this SLR. It is these two aspects that stand them apart as intermediaries for innovation. Because of this commitment—facilitated by the knowledge economy and technological developments—living labs are footloose. They can be on campus [59,71,73,106–109], off campus [9], in an STP [48], on a high street [110], local [65,90,97,111,112], precinct scale [113], urban [100,114–118], suburban [40,66], rural [15], regional [101,105], peripheral [119] or city scale [68,99,102,116,120–123]. They can also be virtual [124].

It is partly this footloose, open and creative element that means that they are potentially difficult to harness at scale: indeed, difficult to harness by policy makers, but also difficult to harness by businesses, universities and the public. These structures are innovative in themselves; each is unique (even with common elements) and each is designed to serve a purpose. Their amorphous shape and shifting nature make them difficult to grasp and initiate at scale. Whilst STPs could be created by policy diktat [76], living labs cannot and as such are more ephemeral and can be a conundrum to universities, business and government. This transformational change of the modus operandii means that a once linear, or apparently linear evolution [60], is now beset by new branches and new forms (such as sustainability labs, urban living labs, and smart cities). These branches and forms are being created at such a pace that the literature is struggling to define them [64], or adequately develop theories to help amortize their existence [125].

- Living Labs and Sustainable Development

In this SLR, living labs (and derivatives) are the partnership structure that is being used successfully to drive social and economic development [62,126]. It is also the structure that is used in the limited number of studies that are using innovation to drive the delivery of sustainable development [19,29,40,73,96,107,109,115,127–132], with the emphasis on both sustainability labs and urban living labs. The literature does not provide guidance for the reasons for this. In a time when the Sustainable Development Goals have been unanimously agreed by the United Nations, it is noteworthy that the literature around developing partnerships for innovation is largely silent on the implications for innovation (an issue also noted by others [29]).

4.2. Attributional Data

As discussed in Section 2, outlined in Table 16, and as defined by Massey (2011), but amended here to meet the needs of an SLR, attributional data relate to comments and discussion about a priori hypotheses or theories that the evaluator brings to the discussion. The data collected are the result of author expertise and assessment, as, in most cases, the theory that underpinned each study went unstated in the study.

Table 16. Categorization and paper breakdown of theories underpinning SLR.

Theme	Theory	Sub-Theory
Economic development [1,8,10,57,76] Economic geography [75,96]	Innovation theory [7,11,15,46,49,53,54,60,62,63,70,78,90,94,110,123,133–136]	Open innovation theory [3,35–37,58,62,64,67,69,97,101,113,118,125,137–140]
		Innovation management theory [100,114,132]
		User innovation theory [141,142]
		Collaborative knowledge production [108,118]
		Service or product dominant [48,66,72,74]
		Frugal innovation [133]
	Growth theory [38,82,102]	Knowledge transfer theory [52]
		Knowledge spill-over theory of entrepreneurship [81]
		Development economics [143]
	Regional development [54,68,83,92,93,106,109,119,120,144]	Agglomeration economics [55,145]
	Management theory [4,42,50,79]	Business design concepts [33]
		Business excellence/total quality management [31]
		Construction management [146]
		Corporate real estate management theory [32]
		New public management theory [41]
	Socio-institutional economics [119]	
	New institutionalism [89]	
	Neo-institutional economics [116]	
Systems Theory [11,91,150,151]	Network theories [34,35,47,112,147,148]	Business network theory [102]
		Actor network theory [149]
	Self-organizing systems [71]	
	Socio technical Systems [73,107]	
	Process-based engineering [38]	

Table 16. *Cont.*

Theme	Theory	Sub-Theory
Planning [124,125]	Transition theory [39,88,92,117]	Urban sustainability transition [99,121]
		Transitions theory (sustainability) [45,96,108,117,129,131]
		Transition management [107]
		Value of sustainable development [40,129,131]
	Design theory [104]	Academic capitalism [71,150]
Social theories	Social practice theory [61,104,109]	
	Social capital theory [40,49]	
	Social network analysis [9,80,84–87]	
	Social entrepreneurship [103]	
	Social institutionalism [51]	
Theories of learning	Interorganizational learning [44,52]	
	Experiential learning [56,127]	
	Informed learning [124]	
	Social learning [98]	
	Audit-based learning [59]	
	Absorptive capacity [43,77]	

The selected papers in this SLR were underpinned by 28 different theories (as detailed in Table 16). The theories supporting the research reveal three intersecting themes which were categorized as economic development, social theories and a thinner vein on theories of learning.

Most studies have an economic theoretical underpinning (see Table 16 for a detailed disposition of the papers and their theoretical underpinning) developed through theories of innovation, economic geography, planning and transitions.

Aligned with economic development is a suite of papers dealing with social theories. This encapsulates both how society develops, but also how individuals interact with partnerships. To some degree, this is the practical element in the development of the papers, as it focuses the papers on the theory of how individuals in society interact with innovation.

The final theoretical category is around theories of learning. This is a shallower vein of research that links through to economic development and social theories but can be divided into two theoretical strands. One is how, particularly, (though not exclusively) universities can use innovation to help deliver learning to their students. The other strand relates to continuous improvement and considers how organizations (individually and collectively) can retain and improve upon their learning by doing.

4.3. Emergent Data

This section of the SLR deals with emergent data. For the purposes of this SLR, emergent data were defined as information that contributes to new insights and hypothesis formulation and are the unanticipated product of connections arising from different articles. They are therefore the result of the consideration of the articulated and attributional data. They are not necessarily supported by an extant body of work, but they do highlight the areas where further research, particularly in the development of theoretical underpinnings is recommended. There are two emerging themes from this SLR that warrant further consideration.

The first relates to the evolution of partnerships for innovation and the potential relationship with globalization of the economy, society and environment. In the literature reviewed for this SLR, the development of partnerships for innovation is depicted as a process largely driven by decisions within the partnership. This SLR has proposed an evolution in the development of partnerships for innovation. However, emerging from this SLR is a nascent, but to date unresearched, relationship between the evolution of partnerships for innovation, the increasing globalization of the economy, society and environment and the development of modes of knowledge production.

The evolution of partnerships for innovation was discussed in Section 4.1.1. The increased globalization of the knowledge economy is a driver of the development of partnerships at the university–industry–government nexus. However, the globalization of society, through widespread adoption of the internet, also appears to be influencing the development of partnerships for innovation (as reflected through work on the quadruple helix [151] as well as wider moves toward open science [152]).

There is also some evidence of the impact of the globalization of the environment in the development of intermediaries for innovation. This SLR revealed a thin vein of work (as did [29]) looking at the use of partnerships for innovation to deliver sustainable development. The link between sustainable development and one form of partnerships for innovation exists, but there is currently little in the literature to provide an understanding of why living labs are the preferred partnership structure to deliver sustainable innovation.

As the same time, there is some discussion of the evolution of modes of knowledge production. Mode 1 is discipline based and produces theoretical knowledge; Mode 2 is transdisciplinary and is characterized by being applied research [14]; Mode 3 is a transdisciplinary ecosystem to enable people, culture and technology to interact across scientific and technological disciplines [151].

In this SLR, no paper explicitly addressed the relationship between the changing external landscape and the evolution of partnerships for innovation, but it would appear there is some form of relationship, and this emerging hypothesis is presented in Table 17. The hypothesis is based on the delivery of the three elements of sustainable development (economic growth, social development and environmental quality) at the same time rather than in isolation from each other. It is this balancing and integration of economic, social and environmental factors that seems to distinguish the living lab approach as the preferred partnership structure used to deliver sustainable development from the other forms of partnership (as discussed in Section 4.1.3).

Table 17. Hypothesis of current relationship between partnerships, globalization and modes of knowledge production.

Evolution of Partnerships for Innovation	Potential Partnership Response to Trends in Globalization			Changes in Knowledge Production
On campus	Economy			Modes 1 and 2
Campus adjacent		Society		Modes 2 and 3
Living labs			Environment	Mode 3

The second theme relates to the discussion in the papers of the triple helix [60], which are driven from a primarily economic perspective (see Section 4.2). The inclusion of a quadruple helix to include the public or citizens did take the model into a more clearly defined social territory, but the debate focused on driving the public perspective in innovation.

The papers reviewed illustrate that only living labs deal with sustainable development. The question remains unanswered as to how society can be confident that the framework driving innovation protects the interests of the global citizen. The interest of the global citizen is encompassed at the strategic level by the sustainable development goals. The relatively light body of research, revealed in [29] and in this SLR, on how to utilize partnerships for innovation to deliver the SDGs reveals a gap in the research literature.

5. Conclusions and Further Research

This SLR has described an evolutionary approach to understanding the development of partnerships at the university–industry–government nexus. The evolution of the partnership structures begins with structures on campus; it then evolves into structures adjacent to campuses and finally to the development of living labs (and derivatives), which are footloose and found in a variety of locations. One reason for the evolution of living labs is the ability to create communities of interest for almost anyone. This evolutionary approach builds on the top-down/bottom-up approach currently described in the literature (see Figure 5). This insight into the evolution of partnerships for innovation is important from a theoretical and practical perspective.

From a theoretical perspective, the evolution in partnerships for innovation opens up the question of, what is driving the evolution. As discussed in Section 4.3, the partnerships for innovation are evolving at the same time as there is globalization of the economy, society and environment and a progressive change in the modes of knowledge production. This insight is helpful in understanding the evolution of partnerships for innovation at the university–industry–government nexus by developing an understanding of how factors external to the partnership may be affecting the evolution of the partnership structures. This finding demonstrates that partnerships for innovation sit within a wider innovation ecosystem that is also evolving.

The SLR also revealed that the partnership structures are evolving at a pace where the literature struggles to define them or develop theories as to their existence. There would be value in understanding the relationship, if any, between these processes to help further understand the factors that are driving the changes in partnerships for innovation.

Practitioners will also benefit from the new understanding of the evolution of partnerships for innovation into increasingly complex structures. Practitioners will be better able to understand how partnerships for innovation are changing, which may provide clearer insights into the most appropriate structure for what they are seeking to achieve which will, in turn, assist them in learning from experience rather than solely by doing.

This SLR also revealed that the predominant focus of the partnerships is economic development underpinned through theories of innovation, economic geography, planning and transitions. There is a stream of research that is focused on economic and social development, and a more limited number of research papers deal with sustainable development (this finding is also reflected elsewhere, for example, in [29]).

In this SLR, the only partnership structure that sought to further sustainable development was the living lab approach (and specifically sustainability labs and urban living labs). This SLR did not reveal the reasons why this is the case, and further research needs to be undertaken to understand why living labs might be considered the preferred structure to promote economic, social and environmental innovation. Further research is also needed to understand the barriers that are standing in the way of the other structures (on campus and campus adjacent) being used to further sustainable development objectives. The literature reviewed in this SLR is silent on the implications of the unanimously adopted Sustainable Development Goals on the development of partnerships for innovation at the university–industry–government nexus, and this gap in the research needs to be filled.

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B.2 Publication 2

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Chapter 30
Business Models for Sustainability in Living Labs

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Abstract There are an estimated 170 active living labs across the globe. All have common elements but not all of them contribute to the delivery of sustainable living. Here we consider the business models of sustainability in living labs (SusLabs). Specifically we review four active living laboratories that are part of the SusLab North West Europe network. We show that the business cases are different for at least two reasons. One is that each SusLab project has a specific focus even though all are seeking to develop energy efficient innovative products, services or systems. Examples of focus include demonstration projects, knowledge generation through research and business to business development. The other is

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that each came about for different reasons which might include significant public or private sponsorship, or through academia-business co-creation, and this too is reflected in the business case. We also show that the business cases are not static, but may evolve over time as opportunities are created and as partners develop a clearer understanding of the potential of each SusLab. We propose that, based on a common definition of a SusLab, theoretical considerations and societal needs, as well as insights from the cases, it should be possible to build a business case for a SusLab which draws on knowledge rather than learning-by-doing.

Keywords Living lab · SusLab · Business case · Triple helix · Sustainable innovation · Path dependency · Transition · Social practice theory

30.1 Introduction

There are at least 170 active Living Labs across the globe (ENoLL 2015). All living labs have specific attributes in common (Salter and White 2013). One is that they aspire towards the innovation of new products or services; they involve close relationships between at least two of the following three sectors: academia, business and society or consumer; they involve co-creating the innovation bringing to bear the expertise of stakeholders on the innovation. However, not all Living Labs contribute to the delivery of sustainable development (Vanaker 2014), nor necessarily progress towards the delivery of some of the recently adopted sustainable development goals (UN 2015).

This chapter only deals with business models of sustainability in Living Labs (SusLabs). Specifically we have reviewed the experience and evidence from four active Living Labs which are part of the SusLab North West Europe (SusLab NWE) network.

30.2 SusLab Case Studies

The SusLab network covers facilities in North West Europe and provides acceleration of innovation for the building industry and society. SusLabs may demonstrate energy efficiency (some are even energy producers) and focus on energy use in and around the home, but they also offer innovation in terms of user and practice, as well as water and resources other than energy. They offer the opportunity for partners to undertake insight research, product prototyping and field testing in a variety of building typologies that represent society at large.

At present the network includes four linked hubs:

1. HSB Living Lab, which is a unique international facility on the Chalmers University of Technology campus in Gothenburg, where researchers and

societal actors can co-create ideas and initiatives for products and services which will enable sustainable living.
2. SusLabNWE Living Lab which is on the London Sustainable Industries Park (London SIP), East London and has been designed, supplied and built by Climate Energy Homes. SusLabNWE commissioned the Institute for Sustainability, working in partnership with the Royal College of Art (RCA) and Imperial College London to procure and run the SusLab.
3. The Concept House Village which is an urban area in Rotterdam dedicated for prototype houses that has been and will be used, tested and evaluated by actual users from surrounding neighborhoods.
4. The SusLab North-Rhine Westfalia (SusLab NRW) Infrastructure which consists of a Smart Home Lab, real home environments and showcase apartments.

The SusLab network is transnational and has dealt with all aspects of valorization through partner and stakeholder dialogue. According to Carlsson (2006) there are few studies of the degree of internationalization of innovation systems so the SusLab NWE is an interesting case to study.

In the following sections we provide a brief analysis of the theoretical underpinning of the SusLab model (Sect. 28.4) before offering an analysis of the different business models that have been developed by the SusLab members (Sect. 28.5). We discuss some of the issues that are common amongst the SusLabs and some that are distinct. Although all SusLabs concern themselves with delivering evidence-based sustainable innovation they all have quite different business models. These different business models are historical and have partly arisen as a result of different motivators for the creation of the SusLab. Interestingly too, it appears that the business model can change over time as relationships and understandings of the potential benefits that can be co-created also develop (Franzen 2015).

30.3 Theory

The ideas behind the development and running of living laboratories vary depending on purpose and this has been reviewed by Dell'Era and Landoni (2014). Their definition of a Living lab concerns the methodology, which does not underpin a business case or model well. We have modified their definition to see the Living Lab as a place rather than a methodology.

> A Living Lab is a real-life place for user[1] co-creation of innovations in knowledge, products, services and infrastructures.

Based on this definition we have identified three theories in particular that are worth further consideration in developing a business case and model for a SusLab.

[1]User is used in general terms and may refer to those living in the lab, if there are any, but equally well to stakeholders from business, society and academia.

The first is the triple helix. This theory owes its existence largely to the work of Henry Etzkowitz and Loet Leyesdorff (2000) from Stanford University who, along with others, developed the notion that business, academia and government (or society in general) all share common interests (Etkowitz et al. 2000; Etzkovitz 2013; Ranga 2015; CEC 2006). Put simply academics produce research which can help business develop innovative products which, if successful, enhances the products competitive advantage, which in turn can deliver societal benefit, such as regional economic development, employment (Nyman 2015; Hessels 2008; Erosa 2012; Gebhardt 2015) and perhaps even the transition to a low carbon economy (Pohl 2008; Hadorn 2006). Although Etzkowitz and his colleagues did not initially dwell on the sustainability issues they argued that if business, society and academia can work closely together then the potential for innovation could be enhanced, delivering benefits to all partners (Etzkowitz 2000). For the partnerships to be successful it is necessary to recognise the different cultures of each organisation (Max-Neef 2005; Nicolescu 2015; Erosa 2012) and different ways of working within different organisations (Jantsch 1970; Pohl 2011). This is why Living Labs are so interesting (Sunitiyoso et al. 2012).

The second is path-dependence theory which is important to understand because it influences the creation of the different business models (Nee and Cao 1999; Bednar et al. 2015; Malm et al. 2012). Path dependency theory sets out how decisions made today are influenced by how previous decisions have been made (Christensen 1997; Senge 1995; Dolan 2015). This does not mean that people cannot change the way they do things, but rather that how they respond will be conditioned by how they have responded in the past (Dolan 2015; Senge 1995). This turns out to be an important issue when we are looking at the different business models adopted by SusLab participants (Vanaker et al. 2014).

Finally, the issue of socio-technical change is important (Geels and Kemp 2007) and in this respect, social practice theory (see Sect. 1.5 for fuller discussion) helps participants to conceptualise environmental behaviour and awareness and design sustainable product-service-systems around the home (Baedeker et al. 2014; Liedtke et al. 2015). This is important because studies in failed innovations have shown that the benefits derived from an eco-product are not fully realised if they have been designed without input from users (Spaargaren 2011). It is for this reason that co-creation is central to the SusLab approach. Involving end users in the design of the product helps to reduce negative rebound effects (i.e. making both the product and the innovation process more efficient) and it is argued that the design of product service systems (PSS) will help with the transition to a low carbon economy (Liedtke et al. 2015 and see Sect. 1.3 for further discussion of these issues). The purpose of the PSS is to focus on the service that is being delivered (for example, the outcome desired might be a warm home) rather than what is producing it (for example, the process of producing and dispersing the output, heat, is the central heating system) and so design focus is on the outcomes service users want produced by a low carbon system. (Liedtke et al. 2015).

30.4 The Business Case

The business case for the SusLabNWE comprises two components. One is the value of being part of SusLabNWE; the other component is the development and maintenance of the SusLab infrastructure itself.

The four SusLab partners have utilised different models, partly as a result of how the individual SusLab came into existence, and partly as the result of what the SusLab was intended to deliver.

As the labs are at the early to medium stage of development (all are active but some of the infrastructure has not yet been built) it is not possible to give details of the benefit outcomes that have been accrued. However, it is possible to set out the value that is expected to be delivered and that forms the basis of the investment that partners have committed. The business cases deal with investment (to create the SusLab), income (from the delivery of services) and value (financial and non-financial benefits derived from the SusLab).

Although each SusLab, and therefore each business case, is different each share some common elements (Etzkowitz and Leydesdorf 2000; Etzkowitz et al. 2000; Etzkowitz 2013). The common elements come largely from being part of the transnational SusLab North West Europe (NWE) network.

30.5 SusLab NWE—The Value of the Network

The SusLab network provides real value to the labs themselves but importantly also to business (both active and future) as well as society. The network was created as the result of a grant from the European Union's Regional Development Fund through INTERREG which is designed to help member states with the development and sharing of information across borders.

Some of the key shared benefits to the member SusLabs of the network is set out in Table 30.1. Business and society also benefit from the value that the network and partnership generate (Ranga 2015). Business benefits from a rigorous, shared process for development of market ready innovation and it follows that business will then be confident that the methodologies are academically robust representing the latest developments in research. Business also gains value from working with potential end-users who are not tied to any organisation in the development of their product or service at various stages (in-sight research, product prototyping and field testing) in the product lifecycle, all of which takes place in a real living place (or near-living in the case of the UK SusLab)—cf. definition of a Living Lab under 8.1.

Society gets value from the network by the development of products, services and product-service-systems that contribute to a sustainable lifestyle (the studied SusLabs are largely focussed on reducing energy usage and carbon emissions) as well as economic benefits associated with successful development of the SusLab

Table 30.1 SusLabNWE—value to partners in the SusLabs of the Triple Helix

Communications	Document ongoing work on SusLab website, including findings from HSB Living Lab, and the Living Lab at the Institute of Sustainability Finalise SusLab book and promote methods at scientific and professional forums as well as at network events
Academic	Work with network to share and co-develop new SusLab methodologies Publication of results and methodology in academic journals Continue to develop SusLab sensor tool kit to support new work (for example Building Technologies Accelerator—building occupancy certification system (BTA-BOCS) pilot projects in office buildings) Continue to develop the SusLab tools such that the toolkit can be easily deployed in the field by sustainable building researchers and practitioners Each SusLab has a measuring and monitoring element and all four can be connected to a single data store and analysis tool to enhance rigour and ensure learnings are shared
Outreach	Maintain network of living labs linked to SusLab website Link SusLab work to regional networks (for example, TU Delft and AMS, Chalmers and HSB housing association) Leverage SusLab network combined with new partners to develop new joint projects Value/weight to partners from increased potential to attract further funding (public and private) for SusLab and product development Enhanced business and academic brand value

and successful product-service-systems (Maassen and Stensaker 2010). This latter value is likely to include new jobs, economic diversification and regional development (Etzkowitz et al. 2000; Leydesdorff and Deakin 2011).

30.5.1 HSB Living Lab, Chalmers University of Technology

The HSB Living Lab model builds on the assumption that the costs for building the facility can be more or less returned to HSB (HSB is a Swedish national housing association) over a longer time horizon. It also builds on the facility attracting companies who are prepared to commit to knowledge generation and development for their own and societal interest. Finally, the model also builds on the facility being attractive to a whole range of researchers at Chalmers, as well as across the SusLab facility (Table 30.2).

The relationship between the core partners (Chalmers, HSB and Johanneberg Science Park) is maintained through a binding ten year agreement signed between the President of Chalmers and the CEO of HSB in Gothenburg. Further, a business to business partnership has been established with 10 partners along the value chain (including architect, building company, IT specialist, bathroom supplier and white goods specialist) who have made a financial and resource commitment to the facility.

The total cost for the building was expected to be fairly typical for a pre-fabricated modular building with a land footprint of 420 m^2 and four floors. However,

Table 30.2 Summary—HSB Living Lab, Chalmers University of Technology

Business model	Knowledge to business and business to business
Partners	HSB Housing Association, Chalmers University of Technology, Johanneberg Science Park. 10 other business and societal partners
Sectoral interest	Local government, academia
Duration	10 years minimum
Purpose	Attracting companies who will commit to research and development for their own and societal interest
Motivation to create the lab	First building demonstration for Johanneberg Science Park

the building has been designed as a flexible living lab and this has meant extra costs which are unlikely to be covered in the lifetime of the building. HSB as an organization was prepared to accept an annual loss for the building over the 10 year period, after which the value of the modules will be roughly 50 % of the new construction cost.

Chalmers researchers have been provided with initial co-funding which has thereby initiated the idea generation between the SusLab partners during the formative process of the HSB Living Lab. Co-funding for the sensor networks based on the SusLab winter pilot has also been an important contribution. Chalmers researchers have obtained and are seeking further national and international research funding to bring the facility up to some 20 active researchers, technical staff and PhD students working in the HSB Living Lab.

The financial sustainability of the HSB SusLab will rely in part on securing the research grants set out above but also by generating an income from working with businesses to develop products and services. This will, in all likelihood, be based on a positive feedback loop whereby successful product development will lead to wider relationships with business which will in turn lead to more grants and which will then lead to more capacity to develop more products. The accommodation itself will be rented out to students (who are happy to be part of the SusLab) at market rates which will cover the costs of running and maintaining the accommodation.

30.5.2 SusLab NRW

The SusLab in North-Rhine Westfalia—led by the Wuppertal Institute—builds on real home environments (in the City of Bottrop). It consists of 4 main pillars: real home environments, the Smart Home Lab, showcase apartments and a new concept for energy efficiency consulting (product-service-system) (Table 30.3).

Insight research and prototyping in real home environments is substantial in a SusLab Infrastructure. One key component for the exploitation has been the development of a methodology for testing products and prototypes in real home

Table 30.3 Summary—SusLabNRW

Business model	Business to business and business to consumers. Embedded in existing, lived-in homes
Partners	Wuppertal Institute, Hochschule Ruhr West, Innovation City Management GmbH
Sectoral interest	Local government; academia; technical college
Duration	On-going
Purpose	Testing products and services in real home environment
Motivation	Developed as part of Ruhr region's commitment to reduce CO_2 emissions by 50 % as well as in response to local economic downturn

environments. The handling and the accuracy of fit of products and services has to be tested within the daily practices of households. The sensor infrastructure consists of data loggers for measuring room climate (temperature, humidity, CO_2 concentration) which are connected to the internet, an internet connected database at the Hochschule Ruhr West (HRW) and software for evaluation of the measured values. This infrastructure was tested in cooperation with the companies RWE and Deutsche Telekom by evaluating the usability and efficiency of their smart home products and systems. The HRW will offer this infrastructure to other companies for further testing of assistive technologies. The aim is to offer investigations in living labs for product improvement as a service to different companies, allowing full exploitation of the facility. The smart home is a 30 m^2 sized lab that is used for testing of the prototypes (proof-of-concept) and for tests of user-interaction before installing them in real homes.

In order to be able to fund the infrastructure, in addition to contracts for co-creating products and services, the German partners HRW, Wuppertal Institute and Innovation City Management GmbH developed the concept of energy efficiency services for communities. The product-service-system is a new concept for energy efficiency consulting for tenants and homeowners. The concept is based on a pre-analysis of the energy efficiency potential by using the evaluation methods developed in the SusLab project. The analysis of room climate delivers a first impression on user behavior, heating system functionality and building insulation characteristics. Based on the results a suitable, economically optimized proposal for increasing energy efficiency can be given to tenants and homeowners.

30.5.3 SusLab Living Lab in London

The SusLab Living Lab in London is a procured element of the project and the Institute for Sustainable Futures is responsible for delivering and managing the facility. Through a competitive process, Climate Energy Homes were chosen as the preferred supplier to design, supply and build the facility. The Institute has worked with others to deliver this facility and improve the exploitation (Table 30.4).

Table 30.4 Summary—SusLab Living Lab in London

Business model	Demonstration project
Partners	Institute for Sustainability (NGO)—responsible for build and management of the living lab, Imperial College, Royal College of Art
Sectoral interest	NGO, Academia, commercial
Duration	Through to 2024
Purpose	Procured project to demonstrate potential of collaboration
Motivation	To provide a living laboratory that is closer to a home environment

The UK has very few facilities which can act as a SusLab outside academic focused facilities, which are usually science laboratory based and not near to a living environment. Hence this facility is welcomed by academics, housing developers and manufacturing companies based in the south east of England. Some wider interest from health authorities has been shown to conduct care in the community type simulations. This facility will be able to emulate a high proportion of the building typology in the UK and therefore participants can relate more easily to experiments or assessments which can be run in the SusLab. This choice is also important as many highly elaborate building systems and cutting edge technologies usually have been tested or have their own research and development back office.

The SusLab aims to attract stakeholders, locally, nationally and EU-wide who are interested to commit to research and development of innovative energy control and awareness technology for their own and the wider benefits associated with being more effective with energy use. The SusLab also aims at attracting research and design practices from local and international academic institutions and institutions that are interested in co-creation and experimentation of solutions in relation to daily life practices.

The original concept was to enable free and full use to encourage the core aspirations of the SusLab project to be delivered over the life of the facility. Therefore, encouragement to use is the key feature and interested parties will be required to reinstate the facility to its current condition on completion of their activities. Encouragement will be on extending use and maintaining the SusLab in at least its current condition, rather than generating an income from activity, other than to cover the operational costs including utilities, cleaning and routine maintenance.

30.5.4 Concept House Village

The Concept House Village (CHV) is an initiative from City Ports Academy Rotterdam and is executed by Rotterdam University of Applied Sciences, Delft University of Technology and the Woonbron Social Housing Corporation. The facility is financially and in-kind supported by the Municipality of Rotterdam.

Table 30.5 Summary Concept House Village

Business model	Sponsorship
Partners	Delft University of Technology, Woonbron Social Housing corporation
Sectoral interest	Local Government, Academia
Duration	Up to 10 years
Purpose	Procured project to demonstrate potential of collaboration. Students involved in design and build
Motivation	To provide a living laboratory that is closer to a home environment

The partners have a long-lasting agreement on the exploitation of the CHV-facility signed by the boards of executive partners which provides a sustainable cost model for exploitation (Table 30.5).

During the first period of its existence in the Netherlands, CHV was financed from different sources. With the financial support from the INTERREG SusLab NWE project, the Dutch Ministry of Economic Affairs (Peaks in the Delta) and the Municipality of Rotterdam it was possible to establish the CHV-facility and to manage the acquisition of new prototypes, to guide the building processes of the prototyping, to coordinate the research program and foster the knowledge transfer.

The basic approach is that the involved consortia finance the prototypes themselves. The two involved knowledge institutes lead the development of the first two prototypes (CH Prototype 1 and CHIBB). The partners of the two consortia financed these prototypes with important additional subsidies from SusLabNWE and Peaks in the Delta.

Those two prototypes serve as a laboratory for the research programs of both knowledge institutes. The on-going research is mainly financed by the institutes' research funds. The prototypes also serve as a learning environment for the Bachelor and Master's students of the institutes. Besides the whole design and development of CHIBB by students of the Rotterdam University of Applied Sciences, students of the Albeda Polytechnic built the CHIBB prototype.

The CHV-facility has agreements with the consortia behind the prototypes about the involvement of students and research staff of both institutes in the development, monitoring, testing and validation of the dwellings.

In 2015 the CHV facility started revising its business model, to become independent from structural public funding, to accelerate the real market application of the results of the prototyping and to become a regional focal point of sustainable building to support the realization of the political ambitions.

30.6 Conclusion

SusLabNWE is in the early stages of development. Some of the infrastructures are still being built but to an extent that will always be the case as the SusLabs will be forever changing. It is therefore not possible to include all values in each of

the SusLab's business models. In part they are benefits that have been valued and accepted as part of the development of the network, but they have not, yet, necessarily been realised. Clearly the business models are evolving. For example London SusLab and CHV are actively refreshing theirs and the SusLab NWR in Germany has identified a new stream of potential income which they are currently developing.

One interesting insight to come from this study of the business models is how the genesis of the SusLab has influenced the business model. For example, part of the motivation for the development of the SusLab NWR was to encourage economic diversification in the Ruhr. As such it initially attracted interest and assistance from Government to develop itself as a SusLab. Similarly the CHV was initiated on the backdrop of public funding, but now that it is established it is seeking to become independent of public funds. Both of these demonstrate, in real terms, the impact of path dependence theory (Bednar et al. 2015).

The other interesting, and unexpected, result of the work has been how relationships with business varies over time, and between businesses (Franzen 2015). By this we mean that different models suit different businesses.

Some are seeking involvement in research that will help to deliver sustainable lifestyles and to change social practices into more sustainable ones. All SusLabs share this opportunity, but the Concept House Village was developed with this market in mind (although it is revising its business model). Effectively CHV set the research program and then invited industry to fund it if they are interested. This is a widely adopted model to fund research in universities.

On the other hand, HSB Living Lab is looking to work with business to develop innovative products and services. The HSB model involves a closer, symbiotic, working relationship between business and academia with both sharing the same project goals but with each having slightly differentiated project deliverables. For example Chalmers researchers will also be drawn to a greater extent to developing the knowledge base within their fields of expertise; business will be drawn by the opportunity to develop and test products using the latest research. All parties seek to deliver the best co-created product, service or system and will gain individual benefits from working together. These outcomes reinforce the benefits predicted by the theory (Pohl 2008; Nicolescu 2015).

Recently completed research has also demonstrated how relationships, values and benefits can change over time (Franzen 2015). A relationship that might start on the basis of developing a new market for a business can with time enable a business the opportunity of developing a product line contributing to a sustainable lifestyle as the relationship between partners develops and matures.

Despite there being close to 170 active Living Labs there is a need to undertake further analysis of the various business models to identify common themes in the business cases, what is included and excluded and if Living Labs with the same aims share the same style of business case. There is the need to share an understanding of the business case development in order that the next generation of Living Labs do not have to re-learn the same lessons that the current generation have learnt. Further research as outlined above will also help to start to address the deficiency in studies of transnational innovation systems as identified by Carlsson (2006).

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If living labs are the answer – what's the question? A review of the literature

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Abstract

The world's economy is becoming increasingly knowledge intensive. This will drive further technological, societal and organisational change. A knowledge intensive economy gives the producers of knowledge – universities – a potentially key role in shaping our future.
However, this paper shows that neither Australian industry, nor universities are good at collaborating for innovation. Change is needed but change is hard, resource intensive and never ending. This paper demonstrates why change is so difficult and suggests steps for success. It demonstrates why effective leadership is central to the change process and suggests further applied research to understand the practical obstacles that are preventing universities from developing partnerships for innovation.
It defines a principle for evidence-based innovation that is fit for the Anthropocene and proposes the sustainable development goals as a measure to understand the impact of university research in order to help move society in the direction society is seeking.
It also pries into the Pandora's box of the role of Universities in partnering for innovation in the Anthropocene and proposes further research on the role of 'leading by doing' on potential partnerships for innovation.

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Keywords: Triple helix; living lab; collaboration; partnership; leadership

1. Introduction

The world's economy is continuing to transition from an age of the "white heat of technology" [1] to a knowledge intensive economy. The pace and rate of change is accelerating [2]. In a knowledge based economy knowledge of how to develop and use it is the key to success. The future should therefore be bright for universities (as knowledge creators and sharers) as well as businesses (knowledge users and sharers). It should be brighter still for those entrepreneurial universities and businesses that work together to combine their skills to innovate in a knowledge intensive economy [3].

However, Australian Universities do not compare well with their OECD counterparts in their ability to collaborate with industry for innovation [4] despite the fact that Australian research outputs are world class [5]. The potential of commercialisation of university knowledge is not being realised [6] and further it is unclear the level of uptake of research by university sector itself to aid commercialisation.

Australian industry too is generally weak at collaborating for innovation. It underperforms OECD competitors on collaboration with its customers, suppliers and universities both internationally and domestically [5] even though innovation was seen, by industry, to be the driver of business success. Industry is also poor at reaching out to other organisations to develop strategic advice relating to the future [7]. However, Australian industry does fund public research in universities at a level that is greater than the OECD average [5].

In addition to the changes that are happening as the knowledge based economy intensifies so too does humanity's impact on the natural environment. Society understands the scale of the impacts due to high quality research outputs from universities,

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industry and elsewhere. If there is to be a close relationship between business and publicly funded universities the innovation it produces needs to be based on evidence of its efficacy in the Anthropocene; if it is not it will be undermining the ability of society to deliver the sustainable development goals endorsed by the UN general assembly in 2015 [8].

1.1. Background

The world's economy is transitioning away from being industry based towards becoming a knowledge economy where knowledge is the predominant factor in driving economic growth. A knowledge economy is only truly possible in a networked world where knowledge can be shared with ease due to the network effect [9, 10].

1.2. Economic impacts

Developed economies are becoming increasingly knowledge intensive [11]. This is a process that has been recognised since the mid-20th century and possibly since the dawn of the Anthropocene in the 1750s [12]. The increasing reliance on, and importance of knowledge and information in product and service development has been widespread and accelerating with over 50% of GDP of major economies being knowledge-based [13]. This may be as high as 70% in some developed economies. However, the ability of economists to track the stocks and flow of knowledge through an economy is still developing [13].

The 'knowledge economy' is a widely used term to signify the intensification of knowledge use in the modern economy [13, 14, 15]). Using the term does not mean that previous economies (ie agricultural or industrial economy) were knowledge free – they were not. Those economies used the available knowledge effectively and were driven by technological innovation [12]. However, the key change was with the adoption of technology horizontally across the economy rather than vertically within trades. For example, the steam engine, and thereby access to power on demand, transformed many industries – from agriculture to textiles to public transport. It was this adoption of 'horizontal' technology (or general purpose technologies [16]) in the 1750s that started the transformation towards a knowledge-based economy; a trend Drucker noted in 1959 when he coined the phrase 'knowledge workers' [12].

The pace if the development has increased markedly in the late 20th and early 21st century with the widespread adoption of the internet [17] and the exponential growth in devices linked to the web (with Intel predicting 20billion devices connected by 2020 [18]). Some argue that proof of its development came with the rise, from the 1960s in the service economy where people with specific knowledge and skills did work for those who did not have it [19]. But the knowledge economy should not be merely defined by its initial association with the service economy. Rather it can be identified by its investments in research and development, education and training and new managerial work structures [13].

1.3. Societal impacts

And while our economy is transforming so to is our society and environment. The knowledge economy is leading to the development of two types of jobs: those jobs where people tell computers what to do and those jobs where computers tell people what to do [20]. The knowledge economy has been blamed for real wage stagnation in the low to middle income groups, stalling service sector productivity growth and increased inequality within society.

In order to maximise the benefits that the new knowledge and information will bring it is essential to adopt new work practices [21, 16]. Investments in technology enable complementary organisational investments which help to improve productivity [11] and these are often associated with workforce changes enabled by the adoption of the technology [22]. The flattening of hierarchies, development of team work where everyone has a voice, and the general empowerment of the workforce can only happen with easy access to knowledge and information are evidence of this new economic era, as well as a clear break with the past industrial based economy [23]. However, the gains from the adoption of new technology are not the same in each organisation – the limiting factor is the ability of the management to create a new environment that will maximise the benefit of the technology [24]. Similarly simply adopting a technological fix without associated process changes can have the opposite effect [16].

1.4. Environmental impacts

The world's environment is also being impacted which Hardin (1968) described as the "tragedy of the (un)managed commons" [25]. Today there are few if any unmanaged commons left and yet humanity's impact on our natural systems is significant and far reaching, even though positive for human well-being and economic growth [26]. The result is that the current geological epoch is referred to as the Anthropocene in view of the impact of humanity [27] – which are so significant as to be geological in scale.

1.5. Emergent 'mega' trends [43] and institutional responses

At the same time as these global changes to the economy, society and environment it is anticipated that economic activity will move from the north to the south and the west to the east [18]. This puts Australia – historically suffering from the "tyranny of

distance" [28] – to being in the same time zone as a quarter of the world's universities. The middle class of this region is expected to expand by over a billion people by 2050 [18]. Politicians have argued that this means that the early 21 century is "the most exciting time to be Australian".

These are indeed exciting times and governments are taking steps to move in a more equitable and sustainable direction. In 2015 the world leaders unanimously agreed to 17 sustainable development goals (SDGs) which, unlike the Millennium Development Goals, all countries will pursue. These goals will guide the world's development over the next 15 years [8]. Further in Paris in 2015 world leaders committed climate action (goal 13) by taking steps to limiting global warming to 2 degrees centigrade (with a further commitment to plan to limit the increase of temperatures to 1.5c).

2. Research aims and methodology

This paper is part of a PhD looking at how universities and industry can better collaborate for low carbon innovation. This paper is designed to give a strategic theoretical backdrop against which further practical work can be tested. It is based upon a high level review of the literature searching under collaboration, living labs, sus labs, innovation, knowledge economy and triple helix through the Web of Science. Papers were read and categorised according to their relevance to both the development of collaborative structures for innovation as well as the delivery of 'future-proofed' innovation.

Within this paper the term 'university' is used to embrace academia in general with an emphasis on research for the public good. Similarly the terms 'business' and 'industry' are used interchangeably to reflect private sector economic activity. There is no significance with the use of the different terms – they are used to reflect the production of knowledge (for the public good) as well as private sector economic activity (largely for private benefit). Also research and innovation are used in this paper as part of a continuum where innovation is seen as taking research and commercialising it to produce a new product or service.

3. Universities and industry – partners in innovation?

Universities and industry have a complex relationship to each other in terms of how they engage with each other for research and collaboration. This is set out in Table 1. The relationship appears to be one of client/customer, or transactional rather than one of collaboration or partnership where each derives value, even if that value is different for each. For example, industry is seen to be weak at collaborating with either other industry or universities. Universities however are good at collaborating with each other (for research) but poor at collaborating with industry for innovation. Universities and industry do work well together however undertaking research. It is not clear, from this literature review, the degree to which such research partnership produces research that derives public benefit or only research that derives private benefit. Industry funds universities to undertake research at a level that is greater than the OECD average. This stands in contrast to Australian Universities and industry being at the foot of the OECD league table for collaborating for innovation. In a knowledge economy collaboration will be the key to success as it is unlikely that any one organisation will hold all the knowledge and business skills to deliver innovative products and services in a networked economy.

Table 1: Australian Universities and business: customers or collaborators?

	Industry	Universities	Customers/students	Suppliers	Use foresight	Research user?
Industry	Collaboration between industry for innovation is weak and localized [29]	Industry fund universities to undertake research at level greater than the OECD and EU28 average. [30]	Industry is weak at collaborating for innovation with its customers [31]	Industry is weak at collaborating for innovation with its suppliers [31]	Industry weak at using strategic foresight [7]	User, and active funder of research
Universities	Collaboration for innovation is amongst the worst in the OECD [15]	Universities are good at collaborating with universities [32]	Investment by universities and students/alumni is the focus of increased attention [33]	Little evidence of universities collaborating with their suppliers for innovation	Unclear as to whether universities use foresight (although they do research scenarios)	Unclear if universities use the research they produce. Initial findings suggest they do not

One interesting absentee from the literature reviewed is the degree to which universities are willing to use their own resources (eg investment in campus development) to either imbed research outcomes or innovation in the p process. In such a case Universities collectively could use their buying power to partner with organisations who are interested in innovation or producing product ready for the Anthropocene. The fact that such a discussion is absent from the literature reviewed suggests this area could be fruitful for developing the next canvas upon which to draw university and industry collaborations.

3.1. Barriers facing collaborators

Universities and business need to become better at collaborating [34], yet resistance to change is deeply engrained within humans [35, 36], as well as the organisations we create [37, 38] and this is, in part, because of the evolutionary desire to not wasting resources by conserving energy.

This has influenced the way we think. Kahneman (2011) argues there are only two ways humans think: one is reactive unconscious thought and the other is contemplative and conscious thought [35]. Being able to react when you are being chased by a hungry tiger is very helpful for survival. However, it is not necessarily helpful when faced with a new situation. New situations possibly need new solutions, and new solutions can only be developed deliberately through conscious thought. Conscious thought takes time, and importantly (in evolutionary terms) energy. Evolution has developed the brain to limit this energy intensive response as much as possible. If new thought is needed the brain seeks to take the conscious thought and convert (through learning) into unconscious action.

The importance of this for organisations is that the same conditions apply. Businesses have processes to efficiently deal with the known situations they face. This is comparable to unconscious thought. If a new situation faces them they need to develop ways to deal with it and this is the equivalent of conscious thought. The new situation will be dealt with, and when it reoccurs it will also be dealt with on the basis of what the organisation did before. In the social sciences literature this is path dependence theory [39] where decisions made today are influenced by how successful decisions were made yesterday. This is also learning by doing [40].

Evidence from neuroscience supports this hypothesis with the discipline of neuroplasticity demonstrating how particularly damaged brains can relearn activities and then, in order to save energy, turn them into reactive thought [41]. The difference that neuroplasticity brings to this stream of research is that it suggests that path dependence theory must, and always will, be a self-fulfilling prophesy as neither humans nor organisations have the necessary resources of energy (or finance) to consciously respond to each situation they face as if it were new. They need an armoury of (unconscious) responses in order to use their energy (or financial resources) efficiently and this limits their ability to respond to new opportunities effectively. Businesses ability to respond is strictly limited by two finite resources: leadership and financial.

Although all organisations are capable of learning, those that do not have established process, or those where processes can be quickly established to match the issue they are confronting, are the most likely to respond the quickest. In innovation – particularly in a situation of disruptive innovation (ie the scenario being faced is entirely new) age is important. Typically young, or small organisations, being the most adept at adopting the change quickly [38] as from their perspective it is not really change in as much as everything is new to them. Importantly, in a disruptive environment first-mover advantage is the key to success [38]. And the knowledge economy is based on disruption – disruption to organisations, society and to technology.

The importance of this insight is that change is and always will be difficult and resisted for evolutionary reasons. However, to make is less entrenched there are key steps organisations and people can take to maximise the chance of successful implementation of change. It is less difficult to deliver when all stakeholders understand what motivates each other and there is a clear understanding of the motivation behind each proposal and what the action is seeking to achieve [21, 42, 43]. Hakkarainen, and Hyysalo (2013) argue for the need to "learn how to interact before interacting for innovation" [67]. Living labs provide the opportunity to address such organisational and cultural barriers as long as there is strong governance model between the partners [44].

In transitioning to a deeper knowledge-based economy will impact technology, society and organisational structures responding effectively to the changes will be key.

4. What is the role for universities in the knowledge economy?

The knowledge economy brings with it technological, organisational and societal innovations and change [45]. In a society dominated by the exploitation of knowledge the role of entrepreneurial universities can be significant at it gives universities the opportunity to partner with business to deliver benefits to society, business and universities. There are many models for such partnership, and the need for such partnerships have been identified for some time [14].

4.1. Living labs

"The OECD science system is facilitating the challenge of reconciling its traditional functions of producing new knowledge through basic research and educating new generations of scientists and engineers with its newer role of collaborating with industry in the transfer of knowledge and technology" [13]

Within Europe the response has been the creation of Living Labs to tackle Europe's declining economic competitiveness and societal challenges [46]. The proposal was developed and agreed under the Finnish Presidency in 2006. Living Labs were developed in response to a shift in the strategic discourse between government and business/universities. In Europe this discourse has been about driving innovation and thence economic development by more effective leverage of public investment in research [14]. This has been productive with significantly higher levels of engagement between business and academia than in Australia [5].

4.2. Evolution of living labs

A Living Lab is a real-life place for user co-creation of innovations in knowledge, products, services and infrastructures. [40] where user is used in general terms and may refer to those living in the lab, if there are any, but equally well to stakeholders from business, society and academia.

There are 170 active living labs in 20 of the 27 EU countries. Most are focused on delivering traditional economic returns (such as jobs, new products and services, regional economic development). But there are sub sets, the so-called Sus Labs [40] and Urban Living Labs [47], Smart Cities [48] that seek to deliver benefits for traditional economic partners, as well as the public good or meeting societal needs [49, 50]. Even though it has been argued that the sustainable development community and living lab communities are "hardly intertwined" [51], increasingly living labs have been seen as an approach to deliver innovation based on societal and end user needs by producing knowledge, goods, services and infrastructure that is fit for the Anthropocene.

Stahlbrost (2012) proposes five key principles, which should permeate all living lab operations: value, sustainability, influence, realism and openness [52]. In the living lab literature there is a discourse about the need to reduce the environmental impact of economic activity in order to deliver value for all stakeholders, with a cleaner environment – rightly - being seen as benefit to society (for example 47, 52, 53]. There is clearly much in this argument. However, this misses the potential power of a living lab to showcase for society, government and business how innovation can be undertaken to meet evidence-based societal and end user needs though partnership between knowledge creators and knowledge users.

The key difference being reducing environmental impact of a product or service does not necessarily equate with meeting science based needs. The clear case in point is the scientific agreement behind the need to reduce carbon emissions. The research community is clear about what society needs to do to prevent anthropogenic climate change exceeding 2 degrees centigrade [54]. A key partner in the living lab community is the research community and the research community should respond to and implement its own research and deliver innovation and mitigation at the same time. It is also for this reason that leadership is so important.

Therefore, in table 2 Stahlbrost's (2012) 5 key principles have been reframed to be explicit about the imperative of delivering the evidence based needs of society as well as helping to deliver progress towards the remaining sustainable development goals.

Table 2. Five key principles underpinning living labs (based on Stahlbrost, 2012).

Principle	Definition
Value	Delivering value for all partners (throughout the value chain)
Sustainability	To follow scientific advice to help maintain a healthy environment as well as to help make progress towards delivery of all of the sustainable development goals
Influence	Acknowledging that all partners have influence in the product innovation process
Realism	Innovation should be conducted in as close to real life environment as possible
Openness	To have an open process to benefit from multiple perspectives

Living Labs offer the potential for universities, academia and society to co-create new knowledge and services together by bringing together various expertise to validate new products and services in a real-life environment [55]. The potential benefits are set out in table 3 below.

Table 3. Partner needs and potential partner benefits

	Need	Benefit
Academia	• Partnering with business for innovation • Higher impact research • Collaboration • Research income	• Enhanced role in a knowledge economy Increase research and teaching output • Higher impact research • Evidence based research • Combined research tracks
Industry	• Lack of capability in collaboration	• Developing competitive edge to build on time, to budget and consistent with SDGs
Government society	• Not meeting evidence based carbon reductions	• Make progress towards delivery of SDGs • Efficient use of investment in research

Dell'Era and Landoni (2014) have categorised 4 underpinning models of living labs in order to help with understanding the array of different business models [56]. Whilst helpful it is the grey areas between the models that will also reveal insights and develop new models [57] . The basic models are:

- Value capturing (using an existing technology in a new way (cf steam engines discussed above));
- Value creating (exploring new technologies);

- Based on open innovation; and
- Based on closed innovation.

Such categorization is useful since living labs cover a wide array of disciplines, products and services: from health, dementia [58], regional small and medium sized enterprises [59], energy and environmental decisions at a community level [60], people with disabilities [61], sustainable domestic technologies [50], eco-cities [62], smart cities [48], business models for successful innovation [63]; architectural [54] and enabling community innovation [64].

Living labs are not a universal panacea for linking business, universities and society and will not be appropriate for all circumstances. For example, highly innovative university spin-offs may not benefit due to the more homogenous nature of their social networks since real value is derived from a diverse social network [65]. But they are a highly flexible, simple and adaptable model for knowledge based innovation.

And more recently living labs have been created to develop professional competencies – this extending the product or service focus to an individual's development [66] . This latter methodology could offer insights to address the need for system changes to complement technology changes [20, 67].

4.3. Business models for innovation

Whilst leadership is critical for a successful living laboratory there is no single model of effective leadership – with different styles benefiting different geographic areas [68] and structure [40]. However, the business model does need to reflect the operationalisation of the living lab (ie open or closed, exploitative or explorative [57])). The question of different business models for different geographic regions does raise issues for the transferability of methodology [69] (rather than the living lab concept), and as such will result in some mix of learning by doing and learning from experiences of others [40]. However, the problems with transferring methodology between regions (and firms) can be reduced by close attention to understanding how each method works [42].

5. Conclusions and further research

In a knowledge-based economy the issue of developing living labs for innovation is a good one, which has been successful elsewhere. It offers a route to effectively commercialise new products and services in partnership with business. It is a model that can benefit all three actors at the same time (see table 2). Ultimately it can offer universities a more central role in society as their impact would be more widespread and visible. However Australian business and universities are poor collaborators. Change is demonstrably difficult to deliver effectively and continuously. It requires good leadership to create the environment that is accepting of change.

The exciting challenge for universities and business is how to collaborate for innovation whilst addressing the economic, social and environmental issues associated with the transition to a knowledge economy in a way that moves society out of the Anthropocene and towards the evidence based future that society has agreed.

Further research is needed in two areas to understand how to improve collaboration with industry. One area is around campus redevelopment. In such a scenario universities are contracting industry to refresh their campuses. As such universities have the opportunity to integrate research and teaching outcomes into the process. To date there is little evidence that this is being done.

The other is around leadership and whether universities adopting research outputs before asking others to adopt them would impact favourably the potential for business to partner with universities. The theory suggests it would.

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B.4 Publication 4

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Do as I say; don't do as I do, let alone do as I've done. A study of Australian Universities' collective response to climate science.

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Abstract

There is no longer a debate about whether climate change is happening due to anthropogenic emissions of carbon – the debate now is around the scale of the likely impact, how to mitigate further increases in temperature and what to do adapt to those impacts.

Not surprisingly, universities have been at the forefront of the climate science. Australian Universities are established to do three things: teach, research and to engage. To varying degrees climate change and its impacts has penetrated all three agendas. Universities are clearly at the forefront of teaching and researching climate change and engaging with society about the science based actions that need to be taken to combat to both mitigate and adapt to its impacts. However, interestingly only 3 Australian universities commit themselves to absolute reductions in carbon from their operations.

This paper will look at the performance of universities in reducing carbon emissions from their operations and seek to identify the reasons why universities do not adopt the science that they say the rest of the society should adopt. It also considers whether Universities performance in partnering internally has implications for their ability to partner with external organisations.

Keywords: climate change, leadership, environmental management, partnership

1. Introduction

The global science community is united about what is forcing climate change: "among papers expressing a position on anthropogenic, or human caused, global warming (AGW), an overwhelming percentage (97.2% based on self-ratings, 97.1% based on abstract ratings) endorses the scientific consensus on AGW." (Cook, 2013)

"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen." (Edenhofer, Pichs-Madruga et al. 2014), 2014). In the 5th Assessment Report the IPCC states that to limit temperature increases to 2 degrees centigrade above pre-industrial levels will require a reduction in carbon (and other long lived green-house gases) of between 40 – 70% reduction from 2010 levels by 2050 and near-zero emissions by 2100. To restrict global temperature increases to 1.5 degrees centigrade would require between a 70 and 95% reduction in carbon and other long lived greenhouse gases on 2010 levels by 2050 (Edenhofer, Pichs-Madruga et al, 2014).

As shown in table 1 Australian Universities were widely involved within this international work with over a third of Australian Universities (excluding CSIRO and BOM) being involved as either authors or review editors for the three working groups that contributed to the final 5th Assessment Report ((IPCC 2014).

Table 1 – Australian Universities contribution as author or review editor to IPCC 5th Assessment Report

Working Group I Physical Science Basis	Working Group II Climate Change, Impact & Vulnerability	Working Group III Mitigation of Climate Change
Australian National University	Griffith University	Australian National University
Antarctic Climate and Ecosystems CRC	Macquarie University	Curtin University
Monash University	University of Melbourne	Monash University
University of New England	University of New South Wales	Murdoch University
University of New South Wales	University of Queensland	University of New South Wales
University of Tasmania	University of Tasmania	
	Victoria University	
Other Australian contributors		
Bureau of Meteorology	Australia/World Bank	Department of Agriculture
CSIRO	Australian Antarctic Division	
	Bureau of Meteorology	
	Climate Risk Consultant	
	CSIRO	

Data from IPCC (2014) 5th Assessment Report

Universities in Australia exist to do three things: to teach, research and engage to get the research adopted. (Counsel 2017). Climate change penetrates all these areas – academics teach the science and social policy impacts, research the likely consequences of a changing climate and ways to adapt to and mitigate that change and, engage in public policy debate to encourage decision makers of the need to take decisions that are cognisant of the science produced by, amongst others, Australian universities.

This paper found minimal evidence of universities adopting their own research (this paper used climate science as a test case) or using their own capital spend to embed this, or any research or to deliver teaching and/or research outcomes in the operations of the university. This poses difficult questions for universities to answer – if climate science represents such an urgent threat to humanity why are Australian universities not applying it to their operations, and why should society adopt research they do not manage to adopt themselves?

It also suggests a further difficulty for Australia to embrace the opportunities of the knowledge economy. Universities in Australia are at the bottom of the OECD rankings for their ability to partner with business for innovation. (OECD 2013). This has been recognised as a key weakness of Australia's innovation framework by both universities (ATN, 2015) and by Commonwealth Government in the National Innovation and Science Agenda (2016). There is little evidence of universities being effective at internal partnering, and this lack of experience perhaps is one reason for their collective poor performance at external partnering as highlighted by OECD and recognised by Government and Universities. The Government and some Universities recognise this weakness by focussing on cross-cutting work in the national innovation strategy (Commonwealth of Australia, 2016) and in University corporate strategies.

However, it is worth noting 2 important points:

- Poor performance collectively should not be interpreted as no performance collectively. There are some universities – albeit a small minority – that are taking the issues seriously; and
- It is not just Universities that are poor at partnering. Whilst Australian business ranks at above the OECD average for funding research at Universities (OECD 2013) it is also collectively weak at engaging with suppliers and customers for innovation (Gahan 2016).

The paper concludes there are 2 clear benefits for universities in adopting their own research where possible – one is that they would be able to more clearly understand the difficulties organisations have in adopting or commercialising research into business models; the other is that universities would

have a stronger voice if they were in a position to encourage others to do as they have done rather than encouraging others to do what the science says, but that they have not done.

2. Methodology

There are 43 Universities in Australia. All Australian Universities websites were accessed between 18 – 20 November 2016 to download their 2015 annual report and financial statements and their forward looking corporate strategies (dates ranging up to 2025). Also, all Government/ University performance agreements were accessed from Department of Education and Training website covering 2014 – 2016 Mission-based Compacts. A limit of 30 minutes was allocated to each university to find and download the data. Where the data was unavailable online (either not found or not published) it was requested by email; follow-up emails were not sent.

All available annual reports and strategies were read and the public commitments in those reports (for example published statements, targets and performance) to partnership and adopting research were recorded and tabulated. Research on climate change was taken as the example for adoption of research due to the agreed status of the science (Cook, 2013), and the applicability of it to campus development (and therefore to capital campus projects). The documents were also searched by keywords (carbon, sustainable, greenhouse, climate change and variants) to understand the importance of sustainability and climate change to each university. They were also searched to understand the importance of collaboration within the university, to the university (words searched were cross-, inter-, multi-, trans-disciplinary and variants) as well as externally with industry, society and government. Each Universities capital spend committed for 2016 was recorded to understand the potential of the sector to use their own capital spend to adopt their own research (for example a university with no forecast capital spend could find it more difficult to integrate teaching and research into campus development).

Due to the incomplete nature of performance data, publicly available performance data was accessed to develop an indicative understanding of the rate of change of emissions of Australian Universities and thereby to understand their success in translating research into impact.

3. Results

Australia has 43 universities, of which 3 committed themselves to absolute reductions in greenhouse gas emissions up to 2020. Based on evidence from Mission-based Compacts covering 2014 – 16, annual report and financial statements for 2016, strategies and corporate strategies (covering a variety of start and end dates but all accessed cover years after 2016) there were essentially 4 groupings of universities:

1. Those with commitments to carbon constraint as well a target for absolute reductions in carbon;
2. Those with commitments to carbon constraint as well a target for reductions in carbon;
3. Those with commitments to carbon constraint but no evidence as to how to deliver the commitment; and
4. Those universities that do not mention carbon or emissions in any of their documentation.

Table 2: Australian University commitments to carbon constraint.

	No.
Universities with a science based commitment[1]	3
Universities with a carbon commitment and published target	12
Universities who make statements but do not provide evidence as to what success looks like	15
Universities who do not mention carbon or emissions	11

[1] This includes RMIT, UTS and Charles Sturt University. CSU is Australia's only carbon neutral university, but there was a lack of clear emission reduction targets at the same time as maintaining carbon neutrality

Total	41[2]

Data from University annual and financial report, strategic plans and mission-based compacts.

Table 2 may portray an unduly positive picture of universities' commitment to embracing climate science. Some commitments would not pass academic, societal or government scrutiny or commentary. Statements like "we will improve energy efficiency between 2015 – 2020", we will "adhere firmly to the principles of sustainability in all we do" or "we will reduce [the university's] operational carbon footprint" are insufficient to be convincing that such universities' are genuinely tackling the issue.

There was also differences within University groupings. RMIT has "since 2008, committed to a target in partnership with Australian Technology Network of Universities to reduce greenhouse gas emissions by 25% by 2020 compared to 2007 as a base". However, this target is not shared by other ATN members (see table 3)

Table 3. Commitment of ATN members to carbon reduction targets.

ATN member	Target
RMIT	reduce greenhouse gas emissions by 25% by 2020 on 2007 as a base
University of Technology Sydney	30% reduction in GHG based on 2007 by 2020/21
Queensland University of Technology	11% reduction in CO_2 per gross floor area (m^2) by 2019 on 2013
Curtin University of Technology	No target
University of South Australia	No target

Data from University annual and financial report, strategic plans and mission-based compacts.

Of the nine Universities that scored the highest ranking of 5 in 2-digit Field of Research code 05 – Environmental sciences in the Australian Research Council's Excellence in Research Australia (Australian Research Council, 2016) seven do not mention carbon or emissions in their corporate strategies; in the same vein 10 of the 12 universities involved in the International Panel on Climate Change 5th Assessment Report (IPCC, 2013) did not include reference to emissions or carbon in their corporate strategies.

There are 10 universities that are required to publish their emission date by the National Greenhouse and Energy Reporting Act (Office of Parliamentary Counsel, 2017a). Analysis of the data shows an increase in total emissions of 4.6% between 2010/11 and 2014/15 as set out in Table 4. Currently this is the only data available.

Table 4: Greenhouse gas emission from 10 largest University emitters.

	Scope 1 GHG (t CO2-e)	Scope 2 GHG (t CO2-e)	Total GHG (t CO2-e)
2010 – 11	103,853	800,006	903,859
2011 – 12	94,758	821,337	916,095
2012 – 13	106,674	826,123	932,797
2013 – 14	103,502	839,198	942,700
2014 - 15	104,316	841,373	945,689
% change over 2010	+0.45%	+5.17%	+4.63%

Data from:
http://www.cleanenergyregulator.gov.au/NGER/National%20greenhouse%20and%20energy%20reporting%20data

[2] Documentation was not available for Torrens University or UCL (Australia). Incomplete documentation for Notre Dame, University of Tasmania.

It is interesting that the pre-eminent research universities working in the environmental science or climate change fields do not apply the science to their own organisations, but are committed to be part of the public debate about such grand challenges.

All universities made commitments to collaborate, debate or work in partnership with a combination of industry, government, society or the communities they serve to develop new research, translate existing research or to improve the wellbeing of society. This commitment to partner with organisations external to the university is a universal desire in the university sector. However, as the OECD, the University sector and Government acknowledge Australian Universities are worse than their OECD counterparts in partnering with external organisations.

The same appears to be the case when considering internal partnerships across the university or to using university spend to deliver teaching or research outcomes or commercialise research.

Australian Universities committed themselves to spend over $1.5bn on capital works during 2016 (see table 5). The Australian Research Council – Australia's principle grant provider – between 2011 and 2013 granted funding worth under $100m to universities to research the built environment and design under Field of Research code 012 (ARC, 2016 p86). There are 8 universities who have committed to using their campuses as a living lab, apply their knowledge to the campus or to help deliver teaching and research outcomes. Those universities will be spending $452m on property, plant and equipment in 2016. There is no evidence in the documents about how the living labs will operate, or how the spend will contribute to teaching and research outcomes. The University of Queensland's corporate strategy is the only one that contains a forward commitment to use the campus as a living lab. (UQ Strategic Plan, 2014 – 17 p21). There are 17 universities that commit themselves, through their corporate strategic plans to cross-silo working. The remaining 26 universities do not make commitments to either cross, inter, multi, or trans disciplinary work.

Table 5: Capital commitments of Australian Universities

	Capital expenditure[3] during 2016 (,000)
Total spend on property, plant and equipment payable within 12 months (all universities)	$1,542,878
Of which capital spend of Universities committed to either using campus as a living lab or applying their knowledge to the campus (UQ, UniSA, UMelbourne, CurtinU, UCanberra, UAdelaide, RMIT, U Tasmania)	$452,737

4. Conclusions

The evidence from this study suggests that Universities have some work to do to put themselves in a position where they can partner effectively with the industry or government to innovate or commercialise their research. Less than 20% of Australian universities are using their campuses to deliver teaching and research outcomes or as a living lab to innovate. Only one university is committed to doing this in the future. Yet Universities will be spending over $1.5bn during 2016 on capital infrastructure. If this infrastructure spend is not used to also drive teaching and research outcomes, or to showcase how to adopt research then it is being spent inefficiently.

Only 3 universities make a commitment for an absolute reduction in carbon emissions, in line with climate science. 90% of universities do not make this commitment (and over 25% of universities do not mention carbon or emissions in their documentation). Yet it is the same Universities that research the subject and pressure Ministers and society at large to take action on climate change.

[3] Capital expenditure contracted for at the reporting date but not recognised as liabilities

Finally, the apparent struggle universities have to partner with themselves could be dismissed as irrelevant. However, Universities are being pressured into developing more effective partnerships with business; if they have little or no experience in either partnering (rather than contracting) nor in implementing or commercialising research then they will not understand the problems businesses face, nor how to overcome such challenges. In an environment where Government is committed to attaching an increasing share of funding to working in partnership with business it would seem adroit for universities to get as much experience as possible in working in partnership across organisations and disciplines. This is not just a job for academics but rather for institutions.

Acknowledgement

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Source data.

Emissions data:
http://www.cleanenergyregulator.gov.au/NGER/National%20greenhouse%20and%20energy%20reporting%20data

All Mission based compacts can be found at: https://docs.education.gov.au/node/34873

University data.

Uni	Annual report – 1st entry Strategic plan – 2nd entry
ACU	http://www.acu.edu.au/about_acu/our_university/publications/annual_reports https://www.acu.edu.au/about_acu/our_university/mission_and_profile/strategic_plan_2015-2020
ANU	http://www.anu.edu.au/about/plans-reviews http://www.anu.edu.au/files/review/anu-2020-strategy.pdf
Bond Uni	https://bond.edu.au/about-bond/university/introducing-bond/bond-university-annual-report https://bond.edu.au/about-bond/university/introducing-bond/bond-mission-strategic-plan
CMU	Not found on website
CQU	https://www.cqu.edu.au/about-us/structure/governance/annual-report http://content.cqu.edu.au/Policy/policy_file.do?policyid=2988
CDU	http://www.cdu.edu.au/about/annual-report https://www.cdu.edu.au/about/strategic-plan
CSU	http://www.csu.edu.au/about/publications/annualreports https://www.csu.edu.au/unistats/university-strategy [2015-16]
CUT	http://about.curtin.edu.au/policy-governance/annual-reports/ http://trove.nla.gov.au/version/196899916
Dea	http://www.deakin.edu.au/adi/strategic-plan/annual-reports http://www.deakin.edu.au/adi/strategic-plan
ECU	http://www.ecu.edu.au/about-ecu/reports-and-plans/annual-reports http://intranet.ecu.edu.au/__data/assets/pdf_file/0005/730328/ECU12439_StrategicPlan_A4_WEB.pdf
Fed	https://federation.edu.au/staff/governance/plans-publications-policies/organisational-data https://federation.edu.au/__data/assets/pdf_file/0010/284248/FedUni_StrategicPlan.pdf
Fli	http://www.flinders.edu.au/about/governance/annual-reports/ http://2025.flinders.edu.au/
Gri	Https://www.griffith.edu.au/about-griffith/governance/plans-publications/annual-report https://www.griffith.edu.au/about-griffith/governance/plans-publications
JCU	https://www.jcu.edu.au/about-jcu/annual-report https://www.jcu.edu.au/about-jcu/university-plan-2013-2017
LaT	http://www.latrobe.edu.au/council/resources http://www.latrobe.edu.au/about/downloads/La-Trobe-Strategic-Plan-November-2015.pdf
Mac	http://www.mq.edu.au/about/about-the-university/governance/annual-reports http://mq.edu.au/our-university/pdf/Macquarie_University_A_Framing_of_Futures_revised.pdf
Mon	http://www.monash.edu/about/who/publications/annual-report http://www.monash.edu/about/who/strategic-plan
Mur	http://www.murdoch.edu.au/About-us/Annual-report/ http://www.murdoch.edu.au/About-us/Strategic-plan/
QUT	https://www.qut.edu.au/about/governance-and-policy/annual-report https://www.qut.edu.au/about/strategic-ambitions/blueprint-for-the-future
RMIT	http://www.rmit.edu.au/about/governance-and-management/governance/annual-reports https://www.rmit.edu.au/about/our-strategy
SCU	http://scu.edu.au/docs/annual_report/ http://scu.edu.au/strategicplan/
Swin	http://www.swinburne.edu.au/about/strategy-initiatives/annual-report/

	http://www.swinburne.edu.au/about/strategy-initiatives/2020-plan/
Tor	Not found on website, requested 20/10/16. No response
UoA	https://www.adelaide.edu.au/publications/corporate/ https://www.adelaide.edu.au/VCO/beacon/
UoC	https://www.canberra.edu.au/about-uc/policy-and-legislation/key-university-documents/annual-reports http://www.canberra.edu.au/about-uc/strategic-plan
UCL	Not found on website, requested 20/10/16. No response
UDiv	https://www.divinity.edu.au/news-events/2016/04/14/2016-annual-report/ https://www.divinity.edu.au/university-of-divinity/about-us/our-vision-and-mission/
UMel	http://publications.unimelb.edu.au/ https://ihouse.unimelb.edu.au/home/features/our-response-to-growing-esteem
UNE	http://www.une.edu.au/about-une/annual-reports http://www.une.edu.au/about-une/executive/vice-chancellor/strategic-plan/strategic-plan-2016-2020/strategic-plan-2016-2020
UNSW	http://annualreport.unsw.edu.au/2015/ https://www.2025.unsw.edu.au/
UNew	http://www.newcastle.edu.au/about-uon/our-university/annual-report https://www.newcastle.edu.au/about-uon/our-university/vision-and-strategic-direction/new-futures-strategic-plan-2016-2025
UND	Not found on Notre Dame's website, requested 20/10/16. No response
UoQ	http://www.uq.edu.au/about/annual-reports http://www.uq.edu.au/about/docs/strategicplan/StrategicPlan2014.pdf
UniSA	http://www.unisa.edu.au/About-UniSA/Corporate-publications/ http://www.unisa.edu.au/About-UniSA/Strategic-action-plan-2013-2018/
USQ	https://www.usq.edu.au/about-usq/about-us/plans-reports/annual-report https://www.usq.edu.au/about-usq/about-us/plans-reports/strategic-plan
USC	http://www.usc.edu.au/explore/reports-and-publications/annual-report http://www.usc.edu.au/explore/vision/strategy-quality-and-planning/strategic-plan-2016-2020
USyd	http://sydney.edu.au/about-us/vision-and-values/annual-report.html http://sydney.edu.au/about-us/vision-and-values/strategy.html
UTas	http://www.utas.edu.au/university-council/university-reports Link to strategy not working. Copy requested 20/10/16
UTS	http://www.uts.edu.au/about/uts-governance/official-publications/uts-annual-report http://www.uts.edu.au/about/university/uts-strategic-direction
UWA	http://www.uts.edu.au/about/university/uts-strategic-direction http://www.web.uwa.edu.au/__data/assets/pdf_file/0010/2538343/114085-VICCHA-StrategicPlan-v3.pdf
UOW	http://www.uow.edu.au/about/publications/index.html http://www.uow.edu.au/ourpurpose/
WSU	https://www.westernsydney.edu.au/about_uws/leadership/mission_goals_strategic_plan https://www.westernsydney.edu.au/about_uws/leadership/governance
VicU	https://www.vu.edu.au/about-vu/publications/annual-reports https://www.vu.edu.au/about-vu/vision-mission-strategy

B.5 Publication 5

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Happy Homes – the Relationship between Homes and Mental Wellbeing: a Review of the Literature

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Abstract

Purpose: This paper set out to uncover the advice available to help people take effective action within our home to improve mental health. The literature and professions are virtually silent on the issue. The professional advice is often the opposite suggesting we should get out of our homes - go for a walk, exercise, play sport, go to the cinema, meet friends, socialise and don't isolate yourself. There is nary any advice about what we can do to our homes to help maintain our mental health. Our home - the physical space where we spend large amounts of energy and time is largely an empty shell for the mental health industry. The message currently presented appears to be "remember to close the door as you leave … to get better". Safe and secure housing is a fundamental pillar of an inclusive and productive society. Yet we don't know for sure what safe, secure, or good housing looks like.

Approach: This paper will begin that dialogue with a comprehensive literature review. The approach adopted to investigate this literature focussed on thinking about what a policy official might experience if they were tasked to develop guidance on steps to improve housings' impact on mental health. Such an individual would not necessarily be aware of the extent of the literature, or of academic disciplines. This approach both made the literature review problematic, but also in some ways also produces a useful insight.

Key findings: The paper concludes that there are three issues that should shape future research: first is the need for transdisciplinary translational research; second is to focus initially on the needs of the resident before the bricks and mortar; third is to endeavour to include the social pillar of sustainable development alongside the economic and environmental.

Originality: This paper is original as it seeks to start a conversation about what self-help measures people can adopt within their homes to protect or enhance their mental wellbeing

Keywords: mental wellbeing, mental health, housing, homes, transdisciplinary research, translational research

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1. Introduction

The prevalence of mental health issues in the community is a concern. Australia suffers from 8 suicides per day with a disproportionate representation in the Aboriginal community. Society's response has been evolving. Mental health is now a topic for public debate. However, the role of the space where people live - the home - has received relatively little attention. The self-help advice that is available routinely refers to the importance of socialising, taking up a hobby and generally getting outside (eg BeyondBlue, 2014, or Better Health Victoria, 2016). Unlike the environmental and economic pillars of sustainable development, and unless you are in the care of the state, there is little to help builders, renovators, landlords, tenants, carers or home owners to take actions to improve the potential for their living space to either prevent a slide down the mental health continuum or just to enjoy better mental well-being.

Table 1: Mental health continuum (developed from Bridging the Distance (2016) and Mental Health Commission of Canada (2016)).

Self-care and social support		**Intervention by health care sector**	
Healthy	Reacting	Injured	Ill
Normal functioning	Common and reversible	Significant functional impairment	Clinical disorder Severe and persistent functional impairment
Normal mood fluctuations. Takes things in stride. Consistent performance. Normal sleep patterns. Physically & socially active. Usual self-confidence Comfortable with others	Irritable/Impatient Nervousness, sadness, increased worrying. Procrastination, forgetfulness. Trouble falling asleep Lowered energy. Difficulty in relaxing. Intrusive thoughts. Decreased social activity	Anger, anxiety. Lingering sadness, tearfulness, hopelessness, worthlessness. Preoccupation. Decreased performance at school or work. Significantly disturbed sleep (falling asleep and staying asleep). Avoidance of social situations Withdrawal	Significant difficulty with emotions, thinking High level of anxiety, Panic attacks. Depressed mood, feeling overwhelmed Constant fatigue. Disturbed contact with reality Significant disturbances in thinking Suicidal thoughts/ intent/behaviour

Possible actions to take at each stage			
Focus on the task at hand Break problems into manageable chunks Identify and nurture support systems Maintain healthy lifestyles	Recognise limits Get adequate sleep, food and exercise Engage in helpful coping strategies Identify and minimise stressors	Identify and understand own signs of distress Talk with someone Seek help Seek social support instead of withdrawing	Seek consultation as needed Follow health care provider recommendations Regain physical and mental health

2. Background

There is longstanding acknowledgement that a person's physical and mental health can be impacted by the place where they live (Chapin, 1951; Novick, 1971). Since human's earliest history those who developed good interventions to keep the unwanted out (hungry animals, weather, enemies) and the wanted in (warmth, family, food, community) survived.

Without good housing people have little chance of maintaining meaningful activities and supportive relationships (Browne & Hemsley, 2010). Housing gives people a physical and cultural space in society and can influence how, and what, they contribute to society (Bendiner-Viani & Saegert, 2007).

3. Methodology

The approach adopted to conduct this literature focussed on providing support for a policy official if they had been tasked to develop guidance on possible steps to improve the houses' impact on the occupants' mental health. Such an individual would not necessarily be aware of the extent of the literature, or the academic disciplines. This approach both made the literature review problematic, and in some ways also produces a useful insight.

Papers were selected through a search of the literature using Web of Science with the terms "housing" and "mental health" (and variants) searching both paper title and content. Not surprisingly this produced a large number of papers. Only those papers that illuminated the relationship between housing and mental wellbeing were selected for deeper analysis.

'Relevant papers' were defined as those that demonstrated an evidenced link between action by a party (e.g. decision maker, policy maker, designer, carer, home owner, or occupier) and the impact on the person living in the house's mental wellbeing. This meant that the issues defined as 'self-care' and 'social support' could be interrogated as well as 'intervention by health care sector' (see Table 1).

These papers came from a range of disciplines largely within the health, planning and built environment sectors. For the purposes of this paper 'housing' was broadly defined so as not to limit by physical structure or tenure and refers to a physical built space designed for human habitation.

'Mental health' has been similarly broadly defined to capture the impacts of interventions across the mental health continuum (see Table 1) that help people move away from treatment and intervention with a particular focus on the self-care and social support end of the spectrum
A total of 96 papers were analysed in detail with findings listed and analysed. Three categories of findings emerged from the analysis relating to the impact of housing on an occupants mental health. The categories were: scope of influence over own life; quality of the home (both build and use) and quality of the neighbourhood.

Topics such as homelessness, alcohol, drugs and their impact on housing and mental health were not included in this review (despite the volume in the literature). Interestingly the large corpus of work on biophilics was only covered tangentially by this literature review in spite of the long established and positive link between impacts of nature on mental health (Sodelund & Newman, 2015).

4. Discussion

There is little in the literature about what healthy people can do within their homes to protect and improve their mental wellbeing (either in new, or existing homes). The main focus of the literature with regard to housing and mental health was:

1. Focus on those marginalised in society (be they at the 'intervention' end of the mental health continuum or in need of housing assistance);
2. The issues that can trigger a decline in physical and/or mental health of home dwellers; and
3. Descriptive research (i.e. we did this and that happened) rather than translational research (i.e. translating the evidence into policy advice).

There is a pervading tendency in the literature of viewing the house as primarily a tool for delivering policy (e.g. meeting carbon targets for the benefit of society). As such much of the discourse is about how to use the home to deliver benefits to a non-static combination of the individual, community and wider society.

In many ways this is what joined-up, or co-ordinated, Government is about – using the most effective tools to deliver policy outcomes. However it also means that the interests of the individual are not subjugated to the interest of the community or wider society. Somehow all interest need to be met – this is why policy making is not simple.

There was no unity in the review about the definition of what a quality house or local neighbourhood looked like, with the majority of the papers focussing on 'poor quality'. However, there are issues identified that are associated with a positive impact on mental health which should therefore be **embraced** by society. There are also issues identified that negatively impact mental health (which should therefore be **avoided** in future). There was a final set of issues identified that were currently too **complex** to be set into a binary function of embrace/avoid and require further work. Under each section we have included a table with a very brief summary of each paper which have been accordingly categorised as 'embrace', 'avoid' or 'complexity'.

This review revealed that there is not a single 'thing' that can be defined as good housing in terms of promoting mental health. Rather it is the result of three interconnected evidenced categories where intervention could be effective in helping to improve an individual's mental health.

These go wider than the simple fabric of the house and the categories are:

- the extent of an individual's influence over their own lives;

- the quality of the individual's housing (which subdivides into both quality of build and of use); and
- the quality of the local neighbourhood.

This is illustrated in Figure 1 which suggests that from the perspective of the individual 'good' housing does not exist in isolation, but is probably better described as a combination of influence, location and quality. Categories may be mutually compensatory (ie. a good neighbourhood may mask a poor dwelling). However, importantly the extent of this compensation is unclear. Policy makers might not have a similar view of good housing – and therein lies the heart of problem. A Commonwealth policy maker with responsibilities for delivering climate change outcomes may view 'good' differently from a care worker at shire level.

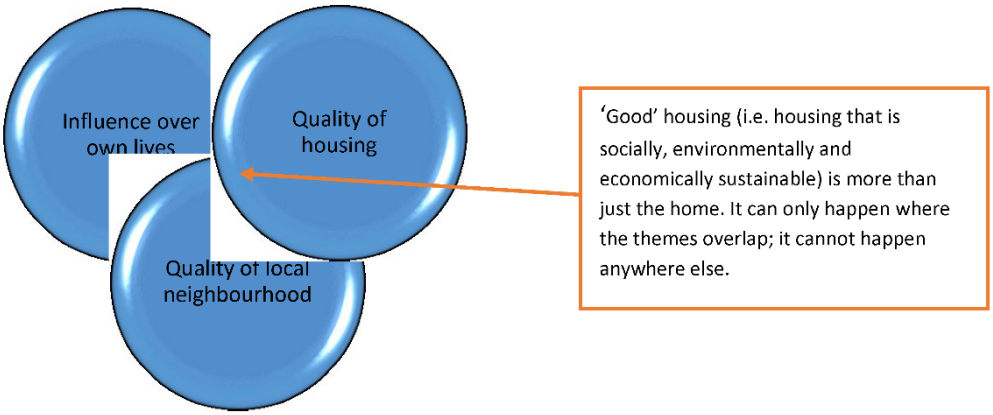

Figure 1: Categories influencing a person's mental health

Category 1: Influence over decisions

Several studies pointed towards the importance of helping people take control over their lives. This was as true for those suffering from drug and alcohol dependence (Allen, 2003) as to the management and maintenance of a residential complex (Mridha, 2015). Control over one's destiny is one of the key's to self-actualisation (Henwood et al., 2015) and papers that focussed on the issue pointed towards the importance of involving residents in the decision making process. However, this is not just about residents and includes involvement of a wider network of stakeholders (Connellan et al., 2013), and further the process of involvement should not be seen as a tick box exercise but rather a continuous endeavour as its impact is additive (Shenassa, 2007). In the leadership literature this is typically referred to as empowerment, but empowerment means that someone still has the power to withdraw authority; Marquet (2012) speaks of emancipation – that is the freedom to make a decision, be it good or bad.

Influence and control comes in many forms ranging from controlling the temperature of the house to decisions about where or how to live. It can mean the development of participatory systems so that a community can have some form of control over its destiny (Shrubsole et al, 2014). The key appears to be the balance between doing something to people and doing something with people, as coercive action is unlikely to be generally successful (Allen, 2003); whereas involvement seems to be helpful (see Table 3 below). Therefore, the development of capacity to deliver individual, designer, carer, health professional and community leadership and dialogue could be an important lever to help maintain mental health across the piece. It is the lack of influence over one's future that can be counter-productive.

Table 3 provides a summary of the literature relating to an individual's influence over decisions that will impact upon them (see methodology for explanation of table headings). It shows that there was general consensus that involvement in decisions is something to be embraced because of the link to a person's mental wellbeing and that it should become pervasive as the issue is not just about 'big' decisions, but also minor irritations (such as setting the temperature of the dwelling (Walker, 2013)).

Table 3: Theme: Influence over decision – summary of the literature

Embrace	Avoid	Complexity
Respect and status of residents (Bond et al., 2012) Inclusive design and self-actualisation (Henwood et al., 2015) Include carers in decision making (Browne & Hemsley, 2010) Management and maintenance (Mridha, 2015) Control is additive (Shenassa et al., 2007) Participatory systems (Shrubsole et al., 2014) Integration of stakeholders in the design process (Connellan et al., 2013) Empowerment – community integration (Nelson et al., 1998) Seeing from the residents perspective (Smith et al., 2015)	Designs to avoid (Connellan et al., 2013) Impact of pre-set thermostats (Walker, 2015) Avoid coercion (Allen, 2003)	Multiple uses and end users to consider (Kearns et al, 2015) Issues around citizenship contribution to society (Sylvestre et al., 2007)

Category 2: Quality of the neighbourhood

The quality of the local neighbourhood was specified by several authors for its impact on people's mental health and wellbeing. The causation ranged from the socio-economic status of the neighbourhood (Fitzpatrick, 2007) through to the impact of new front doors (Curl et al., 2015) to design of new neighbourhoods (Jones-Rounds et al., 2014). The issue of design of something new compared to improving something old was not explicitly covered together in the papers reviewed. However, it was dealt with in separate papers (eg Galea et al., (2007), Fitzpatrick (2007), Jones-Rounds et al., (2014)). That said the provision of quality outdoor space, regardless of the local neighbourhood can have a positive impact – which Gidlof-Gunnarsson and Ohrstrom (2007) demonstrated through the provision of noise 'free' areas, and others (Bendiner-Viani and Saegert, 2007) demonstrated in terms of 'good quality' public space. Understanding the causal pathways will be important in helping to design effective interventions with only intended consequences (Dunstan et al., 2013).

Table 4 summarises the literature on the quality of the community. This is a complex area where there is much descriptive work, but – in this review – less translational work. The dynamics between local community and quality of housing emerges with Jones-Rounds et al., (2014) arguing that a quality exterior environment can offset poor interior environment.

Table 4: Quality of the community – summary of the literature

Embrace	Avoid	Complexity
Community safety (Blackman & Harvey, 2001) Thermal comfort and new front doors (Curl et al., 2015) Sounds (Andringa & Lanser, 2013) Noise free areas (Gidlof-Gunnarsson & Ohrstrom, 2007) Green space (Bertram & Rehdanz, 2015) Location important rather than dwelling type (McCarthy, 1985)	Poor quality neighbourhood (Galea et al., 2007) Lack of green space (Bertram & Rehdanz, 2015) Loneliness resulting from residential structures (Kearns et al., 2015)	Quality of interactions with neighbours and quality of neighbourhood (Dunstan et al., 2013) Planning/health linkages (Wells et al., 2010) Recovery from stress following viewing green spaces (van den Berg et al., 2015) SES of neighbourhood (Fitzpatrick, 2007) Impact on TV watching (MacLeod et al., 2008) Quality of neighbourhoods is important but so too is respect and status (Bond et al., 2012) Economic regeneration alongside property led regeneration (Curl et al., 2015) Good external environment can offset poor interior environment (Jones-Rounds et al., 2014))

Category 3: Quality of the home

The literature revealed much in terms of the link between mental health and housing and develops two sub-themes relating to how the house is designed and how the house is used.

Poor design impacts mental health (Guite et al., 2006); poor housing can also have intergenerational impacts as children's emotional functioning can be impacted (Coley et al., 2013). It also helpfully identified issues that were applicable to only some sections of society – for example for people on low-moderate income 'unaffordable' housing has a negative impact on their mental health (Bentley et al., 2011); or age related mental health impacts and housing (Howden-Chapman et al., 2011).

This literature review did not find what a good or "normal" (Hogan and Carling, 1992) house was in terms of helping people attain or retain a healthy mental state. This is consistent with Bonnefoy (2007) and Evans et al., (2003). However there is some discussion about the development of a housing quality assessment tool (Keall et al., 2010). Although there is not agreement on whether housing quality is more important than housing type (Kearns et al., 2012).

Table 5 summarises the literature relating to the quality of the home. There is a wealth of research on the relationship between the home and mental wellbeing, but there is little that an individual might be able to adopt to enhance their mental wellbeing.
Table 5: Quality of the home – summary of the literature

Embrace	Avoid	Complexity
Heating and new front doors (Curl et al., 2015) Lack of draughts (Blackman & Harvey, 2001) Engage with nature (Maller et al., 2009)	Unaffordable housing (Bentley et al., 2011) Poor design and social features (Guite et al., 2006) Dampness (Hopton & Hunt, 1996) Affordability issue as get older (Howden-Chapman et al., 2011) Crowded homes (Solari & Mare, 2012) Overcrowding (Shenassa et al., 2007) Violence, housing disarray and childhood asthma (Suglia et al., 2010) Crowding (Wells & Harris, 2007) Heat stress (Maller & Strengers, 2011) Poor quality housing has higher impact on mental wellbeing than housing type (Grigg et al., 2008)	Influence of sleep quality, indoor air quality, accessibility, obesity, mould, hygrothermal conditions and energy consumption on mental health (Bonnefoy, 2007) Clustering of ailments in deprived areas (Adamkiewicz et al., 2014) Indoor conditions affect physical health (Veitch, 2008) Housing tenure (Baker et al, 2013) Healing environment MOBE (Hoisington et al., 2015) Home repossession (Pevalin et al., 2009) Quality of interactions with neighbours and quality of neighbourhood (Dunstan et al., 2013) Step down community housing for people coming out of care (Barr et al., 2013) Homes and mental health making the policy links (Johnson, 2005) Affordability and homelessness (Martin, 2015) Health implications of multiple environmental risk exposure (Evans et al., 2003) Patient physical environment (van der Schaaf et al., 2013) Pleasurable and annoying sounds (Andringa & Lanser, 2013) Little research on the positive health effects of exposure to areas of good sound quality (van Kempen et al., 2014) Improvements produce health benefits (Pevalin, 2009) Poor housing & children's emotional functioning (Coley et al., 2013) Unexpected consequences (MacLeod et al., 2008) Community, family and individual influencers (Curtis et al., 2013) Global south might need different research methodologies (Ferguson et al., 2013) House design big impact on use of environment (Marcheschi et al., 2016) Permanent housing has a positive impact (Smith, 2005)

Sub-category – how the house is designed

Housing design quality was shown to be key – good design has a big impact on how people use the house and development (Marcheschi et al., 2016), and the opposite (Guite et al., 2006). Simple things like daylight, view of nature (Maller et al., 2009) and noise (Andringa & Lanser, 2013), being damp free (Hopton & Hunt, 1996) are all important but so too are other variables (such as the interesting emerging work on microbiomes (Hoisington et al., 2015)). Whilst all are part of good design: all can be devalued through occupation. Designing a house to drive behaviours that promote mental health (Marcheschi et al., 2016) or how people use the house (Brunsgaard & Fich, 2016) are clearly important and bring us back to the issues of values raised by Sylvestre et al., (2007).

However new build whilst important will always be less in quantity than the number of existing homes. Housing improvements also deliver benefits (Pevalin et al., 2008) – such as reducing drafts (Blackman & Harvey, 2001), removing dampness (Hopton & Hunt, 1996), renovating bathrooms and kitchens (Curl et al., 2015) as well as providing heating (ibid). Issues such as preset thermostats (Walker, 2015) can have the opposite impact and could result in heat stress which itself has a negative impact on mental health (Maller & Strengers, 2011). Interestingly Curl et al., (2015) showed that the provision of heating can also negatively impact occupants' physical activity which in turn can impact on mental health.

Sub-category - how the house is used

Not being able to afford housing or not able to afford to run the house as designed are both stress inducers and can negatively impact a person's mental wellbeing. Such impacts are clearly delineated according to the ability to pay. Unaffordable housing is seen to be a key issue relating to mental wellbeing for those who are in the low-to-moderate income bracket (Bentley et al., 2011) as is the ability to pay bills (the impact of which changes with age (Howden-Chapman et al., 2011)). Although not directly related to cost, but linked, the link between housing tenure and mental well-being is unclear with studies demonstrating both sides of a different coin. Pevalin (2009) demonstrated that the mental health impact of home repossession is greater if it is owned rather than rented. Whereas Baker et al., (2013) found "little evidence of an intrinsic relationship between tenure and mental health". However, Smith (2005) found a strong link between secure, permanent accommodation and improving mental health.

How occupants use a house can impact on mental wellbeing. Overcrowding (Solari & Mare, 2012) is one such example of how occupants' use of their house can devalue good design and lead to a negative impact on mental health (Shenassa et al., 2007). Reducing overcrowding will improve mental health (Wells & Harris, 2007). Curtis et al. (2013) similarly identifies community, family and individual behaviours as being important influencers. For example production of 'annoying' noise (Andringa & Lanser, 2013) can mitigate design and lead to stress of inhabitants or neighbours.

The behaviour of housing occupants – violence or just disarray - can also have a negative impact on health (Suglia et al., 2015). The issue of how a house is used also links to the earlier discussion over control. Lack of control, or influence over the behaviour of inhabitants or neighbours can lead to negative mental health impacts.

5. Limitations of this work

As the literature is limited about the modifications that can be made to people's homes to improve their mental well-being (or help to protect them from a decline) it is not possible to say with confidence that all such literature has been captured. However the lack of evidence in the literature is a theme that has been present – and commented upon – since the research of Evans et al. (2003).

The approach of this literature review however, did mean that much literature on the role of intervention in prisons, police stations and similar institutions were not included. Similarly, there is much in the literature about 'green offices' and how green office space may or may not help to improve the productivity of, and environment for office workers (e.g. Thatcher and Milner (2012)). This paper has not sought to identify the research in the green office space and apply it to private housing but there are very likely to be transferable lessons.

Similarly this review did not pick up the body of work on biophilics. This is a rich stream of work that could well inform translational research to deliver benefits along the mental health spectrum as well as cover new and existing homes.

The vast majority of the papers reviewed were based in a western context with Marais and Cloete (2014), Marais et al., (2013) and Mridha (2015) being the exceptions. It is important to recognise that the research methodologies used in western cultures are not necessarily directly transferrable to other regions of the world (Ferguson et al., 2013; Marais et al., 2013)

6. Conclusion

There are three over-arching observations from this literature review.

Firstly is the need for transdisciplinary (Jantsch, 1972) and translational research (Nelson et al., (1998), Osypuk (2014) and Veitch (2008)). Transdisciplinary because the literature review revealed the difficulty faced in capturing all the relevant disciplines; and translational because there is a continued and evidenced need to start developing interventions that can help people in the self-help/social support end of the continuum. Such translational research needs to focus on as a minimum the individual and their social support as delivery pathways. Ideally such studies should be longitudinal (Pevalin et al., 2008). Either way, it cannot be acceptable from a policy perspective to leave those issues largely uncovered.

Secondly, Novick (1971) spoke about the need to focus on the person. This still applies today, but we should be focussing first on the individual and their needs. In the UK Government there is a discourse of 'policy making as if people matter'. This needs to be the case for work on housing. A focus on the person first and then the bricks and mortar is essential. If policy makers do not do this then we will continue to deliver the sorts of social unintended consequences identified by Shrubsole et al. (2014).

Thirdly – linking both the above points – housing and mental health policy development, and particularly housing building codes and guidelines seem to focus predominantly on the economic and environmental pillars of sustainable development. Inclusion of the environmental pillar over the last couple of decades represents real and genuine progress; the next step needs to more explicitly include the social pillar.

7. Recommendation for future work

With so many interdependencies between the three themes of influence, design and community it is difficult to identify a way to break down the vectors of causation. However, a productive transdisciplinary route is available to the innovative university. A living lab – perhaps based in either new and/or existing student accommodation could help to understand the interdependencies within and between the themes. Such a project could start the process of developing translational research to help update building codes and design guidelines with those actions that can be undertaken, particularly at the self-help social care end of the continuum, to promote mental well-being.

8. Declaration

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Appendix C Copyright

C.1 Publication 1

Burbridge, M. & G. Morrison (2021) A systematic literature review of partnership development at the university-industry-government nexus. Sustainability 13, no. 24: 13780. https://doi.org/10.3390/su132413780

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A Systematic Literature Review of Partnership Development at the University–Industry–Government Nexus

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Abstract

The increasingly entrepreneurial intent of universities implies the commercialization of knowledge and innovation through the triple helix of interactions between universities, industry and government. However, there remains a lack of clarity concerning best practice partnerships for innovation. This systematic literature review (SLR) provides insights onto the development of partnerships at the university–industry–government nexus and builds on the existing top-down/bottom-up approach for the creation of intermediaries of innovation. The SLR describes the evolution of these intermediaries, which is driven both by criteria set by partners and the globalization of the knowledge economy. This SLR reveals that the partnership structure most likely to further economic and broader societal goals is the living lab with the inherent focus on open innovation and co-creation. This SLR reveals that the living lab structure (and including sustainability labs and urban living labs) is the partnership structure utilized for innovation that addresses economic, social and environmental goals. Two areas are recommended for further research. One concerns the development of a deeper understanding of the relationship between the evolution in the structures of partnerships for innovation and how it is influenced by the globalization of the economy, society and environment, and changing modes of knowledge production. The other is to better understand why the living lab approach to partnership creation is best suited to the delivery of sustainable development objectives and how this learning can be applied to other models of partnership development at the university–industry–government nexus. View Full-Text

Keywords: triple helix; innovation; partnership development; sustainable development

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C.2 Publication 2

Burbridge, M., G Morrison, M. van Rijn, S. Silvester, D. Keyson, L. Virdee, & C. Baedeker (2016). Business models for sustainability in living labs. In: Keyson D., Guerra-Santin O., Lockton D. (eds) Living Labs. Springer, Cham. https://doi.org/10.1007/978-3-319-33527-8_30

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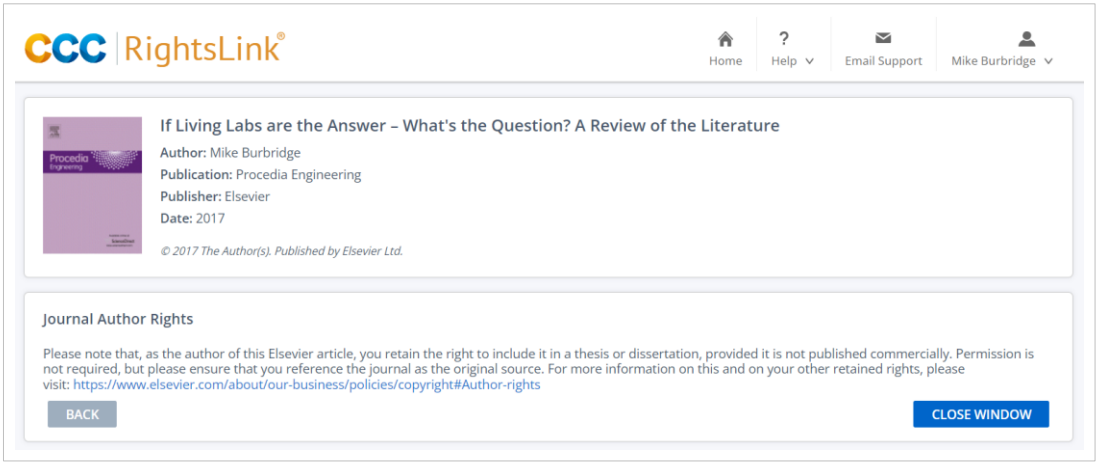
C.3 Publication 3

Burbridge, M (2017). If living labs are the answer – what's the question? Procedia Engineering, Vol 180 pp 1725 – 1732



C.4 Publication 4

Burbridge, M. (2018). A Study of Australian Universities' Collective Response to Climate Science. In: Sayigh A. (eds) Transition Towards 100% Renewable Energy. Innovative Renewable Energy. Springer, Cham. https://doi.org/10.1007/978-3-319-69844-1

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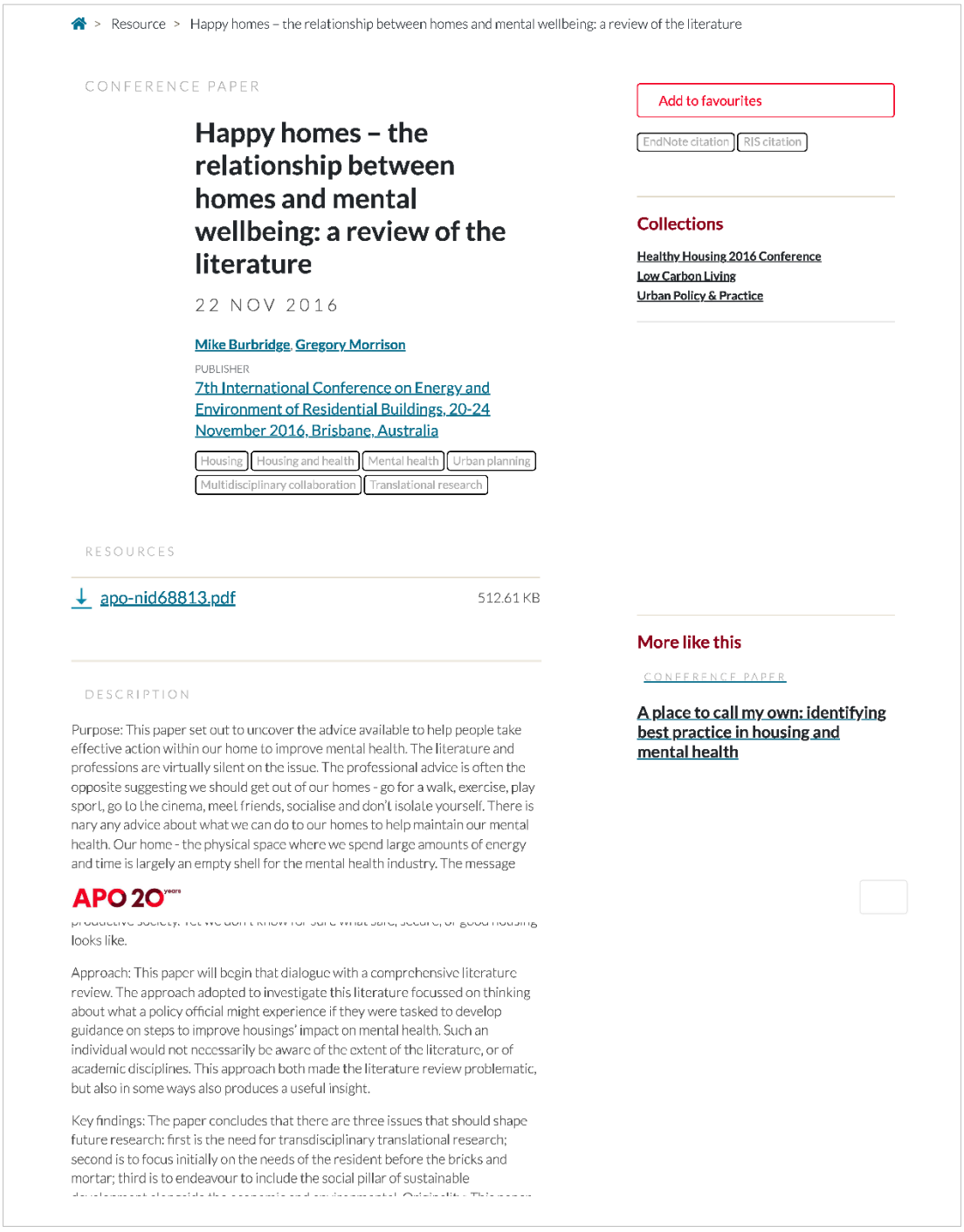
C.5 Publication 5

Burbridge, M. & G Morrison (2016). Happy Homes – the Relationship between Homes and mental wellbeing. Proceedings of the 7th International Conference on Energy and Environment of Residential Buildings, edited by Miller, W., Susilawati, C. and Manley, K. Brisbane: Queensland University of Technology, Australia.



> Resource > Happy homes – the relationship between homes and mental wellbeing: a review of the literature

CONFERENCE PAPER

Happy homes – the relationship between homes and mental wellbeing: a review of the literature

22 NOV 2016

Mike Burbridge, Gregory Morrison

PUBLISHER

7th International Conference on Energy and Environment of Residential Buildings, 20-24 November 2016, Brisbane, Australia

Housing | Housing and health | Mental health | Urban planning | Multidisciplinary collaboration | Translational research

RESOURCES

apo-nid68813.pdf 512.61 KB

DESCRIPTION

Purpose: This paper set out to uncover the advice available to help people take effective action within our home to improve mental health. The literature and professions are virtually silent on the issue. The professional advice is often the opposite suggesting we should get out of our homes - go for a walk, exercise, play sport, go to the cinema, meet friends, socialise and don't isolate yourself. There is nary any advice about what we can do to our homes to help maintain our mental health. Our home - the physical space where we spend large amounts of energy and time is largely an empty shell for the mental health industry. The message

APO 20

looks like.

Approach: This paper will begin that dialogue with a comprehensive literature review. The approach adopted to investigate this literature focussed on thinking about what a policy official might experience if they were tasked to develop guidance on steps to improve housings' impact on mental health. Such an individual would not necessarily be aware of the extent of the literature, or of academic disciplines. This approach both made the literature review problematic, but also in some ways also produces a useful insight.

Key findings: The paper concludes that there are three issues that should shape future research: first is the need for transdisciplinary translational research; second is to focus initially on the needs of the resident before the bricks and mortar; third is to endeavour to include the social pillar of sustainable

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