Campus Living Labs in Transition

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DOI
10.4233/uuid:4757dd92-05a3-4fc5-8a1b-4b67d33f2421

Publication date
2024

Document Version
Final published version

Citation (APA)
Herth, A. (2024). *Campus Living Labs in Transition*. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:4757dd92-05a3-4fc5-8a1b-4b67d33f2421

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Cover design and layout: © evelienjagtman.com
Printing: Ridderprint, the Netherlands

ISBN (print): 978-94-6384-667-7
ISBN (ebook pdf): 978-94-6384-669-1

An electronic version of this dissertation is available at https://doi.org/10.4233/uuid:4757dd92-05a3-4fc5-8a1b-4b67d33f2421 or https://repository.tudelft.nl/

CAMPUS LIVING LABS IN TRANSITION

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus
Prof.dr.ir. T.H.J.J. van der Hagen; Chair of the Board for Doctorates
to be defended publicly on
Wednesday 4 December 2024 at 12:30 o'clock

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Keywords:
Climate neutrality, Campus as a living lab, Higher Education Institutions, Sustainable transitions, Carbon footprint, Energy transition, Co-creation and innovation, Transdisciplinary approaches

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SUMMARY

Co-creating a climate-neutral future through campus living labs

To achieve the imperative of limiting global warming to 1.5 degrees Celsius and achieving net-zero CO_2 emissions, sustainable transformation across all sectors is crucial. In that context, Higher Education Institutions (HEIs) play a vital role not only in generating and disseminating knowledge to accelerate these transitions but also in showcasing them within their own organizations. Many HEIs aim to become climate neutral within the next decades. However, implementing solutions for complex problems like climate change mitigation is challenging due to the involvement of multiple stakeholders and interconnected effects. These interconnected effects refer to how various factors and actions influence one another. For example, changes in energy policy can have economic, social, and environmental effects simultaneously. Addressing one issue often has ripple effects on other areas, necessitating an integrated approach. This complexity makes it difficult to isolate problems or solutions, as each element is linked to others, creating a web of dependencies. Therefore, addressing these challenges requires inclusive approaches integrating diverse forms of knowledge, including practice-based knowledge, alongside academic expertise, ensuring that solutions are comprehensive and consider a broad spectrum of impacts.

So-called living labs are such an inclusive approach. Living labs are transdisciplinary settings designed to address complex societal problems by involving stakeholders from governmental, academic, corporate, and user realms in experimentation and innovation toward sustainable solutions. They operate in real-world settings, for example, in urban areas. This dissertation focuses on living labs situated on HEI campuses. Such campuses are particularly suitable for living labs due to their ample space, extensive infrastructure, diverse stakeholders, cutting-edge knowledge, and inherently fostering a positive environment for experimentation, knowledge generation, and innovation.

Despite the growing popularity of campus living labs in research and practice, understanding their complex inner workings, effectiveness, and impacts remains challenging due to their heterogeneity and context dependency. Research on living labs in HEI campus environments is still nascent. The conceptualization and facilitation of campus living labs are not yet fully understood, highlighting the need for a deeper exploration of their intricacies so that they can support transitions toward climate neutrality within HEIs and beyond. Different conceptual frameworks are needed to explore HEIs' diverse approaches to contribute to sustainable transitions effectively by utilizing living labs. For example, utilizing the campus as a living lab rather than facilitating single, stand-alone living labs on campus.

An example where the challenges of transitioning to a climate-neutral campus and facilitating campus living labs converge is the Delft University of Technology (TU Delft). Here also, the question of enabling living labs within the campus environment to effectively contribute to climate neutrality (on campus and beyond) remains unanswered.

Against this background, **this dissertation aims to understand how campus living labs can contribute to the transition toward climate neutrality**. The research addresses the following four sub-questions, focusing on examining challenges faced by campus living lab participants from an intra-organizational perspective, identifying enabling factors for campus living labs across different development phases, exploring the concept of the Campus as a Living Lab, and pinpointing impactful focus areas for campus innovations by analyzing TU Delft's carbon footprint and emission hotspots.

- What challenges are encountered by participants in on-campus living labs, particularly from the intra-organizational HEI perspective?
- Which factors enable the well-functioning of on-campus living labs, and how do they vary in significance throughout living labs' different phases of development?
- How can the "Campus as a Living Lab" be conceptualized, operationalized, and practically implemented?
- What is the complete carbon footprint in the case of the Delft University of Technology, including both direct and indirect emissions?

Each of the subsequent chapters addresses a specific sub-question. The explorative nature of the questions is reflected throughout the chapters, which employ different methods. The dissertation progresses from an internal investigation focused on the Delft University of Technology in Chapters 2 and 3 to a broader perspective in Chapters 4 and 5. This expansion includes considering other campus cases, conducting a systematic literature review, and engaging with an international Community of Practice.

Research findings

Chapter 2 quantifies the direct and indirect carbon emissions of the Delft University of Technology to establish a baseline for reduction strategies towards climate neutrality. In previous studies, the hard-to-calculate indirect emissions from the up-and downstream activities often were disregarded, resulting in a scattered picture and incomparable results. This chapter presents a comprehensive analysis employing a process and economic input-output analysis. The results highlight the university's carbon hotspots, such as real estate and construction, natural gas use, and procured equipment. About 80 % are indirect emissions, which emphasizes the importance of integrating these emissions and the supply chain stakeholders for better-targeted and impactful reduction strategies. Besides the hotspot identification for the Delft University of Technology, the results are a transparent reference point for other universities and thus contribute to better comparable results. This chapter also points to problems in the calculation methods, suggesting that future research should develop better-suited ones.

Chapter 3 explores the opportunities and challenges of on-campus living labs involved with experiments concerning the energy transition. Despite their increasing popularity, much remains unclear about their way of operation and their potential to innovate. Research into the embeddedness of living labs in HEIs is limited and at an early stage, posing a challenge to their facilitation in a campus context. This chapter examines six on-campus living labs at the Delft University of Technology through semi-structured interviews with intra-organizational stakeholders ranging from researchers to operational staff members. Results show various living lab-internal and external challenges. Such internal challenges include the need for effective stakeholder collaboration, involving users from the beginning and ensuring a clear living lab setup, along with well-coordinated administration and effective governance structures. External challenges relate to the difficulty of embedding living labs into the university's organizational structure, their coordination and resource allocation on the university level, and tensions between academic and operational operations and processes. Despite these challenges, we conclude that a university campus is still a fruitful place for living labs to co-create and innovate. By creating awareness and understanding of the challenges living labs face in this context, future initiatives may be facilitated better so that they are able to unlock their potential to innovate and contribute to societal challenges sooner rather than later.

Chapter 4 moves beyond individual cases and investigates enabling factors for on-campus living labs, addressing the growing need for knowledge about facilitating these settings. Most living lab studies are confined to single cases and contexts, so their results are difficult to generalize. This chapter employs a systematic literature review to provide a broader perspective and extract enabling factors applicable across various HEI contexts. It also emphasizes the importance of considering living labs' developmental stages and their specific facilitation requirements by exploring the factors' salience throughout these phases. Sixteen enabling factors and a deep dive into the five most pertinent ones are presented. These five represent the core of living labs themselves: stakeholders and networks, coordination on the organizational level, a conducive work culture, co-creation and collaboration, and suitable methods and practices for living labs. Further, all factors' relevance during the preparation, start, value creation, and transfer and scaling phases are assessed through the input of an expert panel. To that end, we developed a mapping exercise, which can in itself serve as a discussion tool for living lab practitioners. Our results suggest that some factors like stakeholders & network, learning, and a shared understanding are vital throughout all phases. Furthermore, distinct factors are deemed more influential in specific phases. The initiation phase relies on leadership, coordination, stakeholder engagement, a conducive work culture, and funding. In contrast, operational phases are enabled by shared understanding, internal management, stakeholder collaboration, methodological appropriateness, and evaluation. Lastly, the dissemination phase hinges on transfer, scaling, evaluation, learning, and bridging stakeholders and contexts. These insights contribute to a better understanding of enabling factors for campus living labs during different phases of development, offering tailored guidance for stakeholders while stressing adaptability to local contexts. Subsequently, campus living labs may be better equipped to generate sustainable solutions effectively.

The key findings from Chapters 3 and 4 highlight the importance of coordination, knowledge exchange, and organizational integration of campus living labs. Nevertheless, there remains a need for a comprehensive understanding of their implications and implementation requirements, particularly when Higher Education Institutions aim to harness their sustainable transformation potential beyond single initiatives structurally. As such, there is a growing demand for concepts and tools that allow moving from facilitating individual living lab initiatives to a more comprehensive approach. In response to these calls, *Chapter 5* draws on insights from an international Community of Practice, existing literature, and three university cases, while applying various iterative adaptation and validation cycles. As a result, the conceptualization of the "Campus as a Living Lab" as distinct from the typically applied approach of individual "Living Labs on Campus" is presented. The Campus as a Living Lab is an integrated approach that fosters

synergies, knowledge exchange, and cross-fertilization among various campus innovation initiatives. The entire campus and the organization serve as a living lab, functioning as fertile ground for sustainable experimentation and innovation. This chapter outlines the initial development process and provides a context-adaptable tool for launching the Campus as a Living Lab. The preparation phase focuses on establishing the preconditions by analyzing the current landscape of living labs, innovation projects, testbeds, and experiments on campus, assessing core competencies, identifying critical internal and external actors, discussing values, developing a strategic framework, and outlining the potential impacts of the approach. The start phase involves practical steps to integrate the Campus as a Living Lab within the organization, such as establishing governance structures, assigning roles, mandates, and responsibilities, allocating resources, developing success indicators, planning evaluation cycles, defining timelines, and developing a financial framework. This chapter clarifies the different approaches HEIs can take towards living labs on their campuses and supports them in establishing the Campus as a Living Lab, leveraging their unique position to drive sustainable transformation.

Main conclusions

Campus living labs are promising settings for fostering sustainable solutions. However, creating the necessary local conditions for them to flourish demands efforts at both the internal living lab and HEI organizational levels. A preliminary analysis of the findings from Chapters 3 and 4 suggests that the top five enabling factors identified in Chapter 4 can effectively address all challenges categorized in Chapter 3. This emphasizes their relevance as a first starting point in addressing both internal living lab and contextual issues. Further rigorous research should investigate and validate these connections. Additionally, this work's findings prompt several recommendations, including engaging relevant stakeholders from the beginning, recognizing and adapting to the unique nature of living labs (compared to traditional projects) within the organization, embedding campus living labs structurally, establishing the Campus as a Living Lab systemically, and fostering learning networks among campus initiatives and other HEIs pursuing similar approaches.

Campus living labs can drive climate neutrality by addressing major emission sources like the built environment, energy consumption, and embodied emissions from procured equipment and ICT. To function effectively, it is essential to eliminate organizational barriers and integrate stakeholders early on. More than just implementing stand-alone living labs on campus, HEIs must comprehensively integrate them into their operational, research, and educational structures to fully harness their potential and that of the campus environment. Transforming the campus into a living lab fosters a collaborative learning network, amplifying innovation and potentially extending impacts beyond the campus. Future research should evaluate the long-term effectiveness of campus living labs and the Campus as a Living Lab in achieving climate neutrality.

Significant changes have taken place at TU Delft in the meantime. These involve including scope 3 emissions in yearly carbon footprint reports and establishing a governance framework for campus innovation, highlighting the university's commitment to sustainability. These efforts offer a promising outlook for the potential of living labs to accelerate progress toward climate neutrality.

By offering tailored guidance and emphasizing the importance of local adaptation, this dissertation seeks to harness the innovation potential of living labs in HEI contexts to drive sustainable transitions. It may serve as a base for immediate action and encourages co-created, dynamic, and iterative further development. The time for action is now.

Samenvatting

SAMENVATTING

S

Co-creëren van een klimaatneutrale toekomst via campus living labs
Om de opwarming van de aarde tot 1,5 graden Celsius te beperken en netto nul CO2-uitstoot te realiseren, is duurzame transformatie in alle sectoren essentieel. In dit verband spelen Hoger Onderwijs Instellingen (HOI's) een cruciale rol, niet alleen door kennis generatie en verspreiding om deze transities te versnellen, maar ook door ze binnen hun eigen organisaties te demonstreren. Veel HOI's streven ernaar om binnen enkele decennia klimaatneutraal te worden. Het implementeren van oplossingen is echter uitdagend door de betrokkenheid van meerdere belanghebbenden. Veranderingen in energiebeleid, bijvoorbeeld, kunnen tegelijkertijd economische, sociale en milieueffecten hebben. Het aanpakken van één probleem werkt vaak door op andere gebieden, wat een geïntegreerde aanpak noodzakelijk maakt. Deze complexiteit maakt het moeilijk om problemen of oplossingen los van elkaar te zien, omdat alles met elkaar verbonden is, wat een netwerk van afhankelijkheden creëert. Daarom is een inclusieve benadering vereist, die verschillende soorten kennis integreert, waaronder praktijkgerichte kennis, naast academische expertise, om ervoor te zorgen dat de oplossingen breed en alomvattend zijn.

Living labs zijn een voorbeeld van zo'n inclusieve aanpak. Living labs zijn transdisciplinaire omgevingen die zijn ontworpen om complexe maatschappelijke problemen aan te pakken, door belanghebbenden uit overheids-, academische, zakelijke en gebruikersdomeinen te betrekken bij experimenten en innovatie op zoek naar duurzame oplossingen. Ze opereren in de praktijk, zoals stedelijke gebieden. Dit proefschrift richt zich op living labs op HOI-campussen. Dergelijke campussen zijn bijzonder geschikt voor living labs vanwege hun grote ruimte, uitgebreide infrastructuur, diverse belanghebbenden, toonaangevende kennis en een positieve omgeving voor experimenten, kennisontwikkeling en innovatie.

Ondanks de toenemende populariteit van campus living labs in onderzoek en praktijk, blijft het een uitdaging om hun complexe werking, effectiviteit en impact te doorgronden, vanwege hun heterogeniteit en contextafhankelijkheid. Onderzoek naar living labs op HOI-campussen staat nog in de kinderschoenen. De conceptualisering en facilitering van campus living labs zijn nog niet volledig uitgewerkt. Dit benadrukt het belang om hun complexiteit beter te onderzoeken, zodat ze de transitie naar klimaatneutraliteit binnen en buiten HOI's kunnen ondersteunen. Verschillende conceptuele kaders zijn nodig om

de diverse benaderingen van HOI's te verkennen die effectief kunnen bijdragen aan duurzame transities door middel van living labs. Bijvoorbeeld door de hele campus als een living lab te gebruiken, in plaats van enkel afzonderlijke, op zichzelf staande living labs op de campus te faciliteren.

Een voorbeeld waar de uitdagingen van de transitie naar een klimaatneutrale campus en het faciliteren van campus living labs samenkomen, is de Technische Universiteit Delft (TU Delft). Ook hier blijft de vraag open hoe living labs binnen de campusomgeving effectief kunnen bijdragen aan klimaatneutraliteit, zowel op de campus als daarbuiten.

Tegen deze achtergrond **heeft dit proefschrift als doel te onderzoeken hoe campus living labs kunnen bijdragen aan de transitie naar klimaatneutraliteit**. Het onderzoek richt zich op vier deelvragen, waarbij de nadruk ligt op het onderzoeken van de uitdagingen waarmee deelnemers aan campus living labs binnen de organisatie worden geconfronteerd, het identificeren van factoren die campus living labs in verschillende ontwikkelingsfasen mogelijk maken, het verkennen van het concept “Campus als Living Lab” en het vaststellen van belangrijke focusgebieden voor campusinnovaties door middel van een analyse van de koolstofvoetafdruk en emissie-hotspots van de TU Delft.

- Welke uitdagingen komen deelnemers aan campus living labs tegen, met name vanuit een intra-organisatorisch HOI-perspectief?
- Welke factoren maken het goed functioneren van campus living labs mogelijk, en hoe variëren deze factoren in belang gedurende de verschillende ontwikkelingsfasen van deze labs?
- Hoe kan het concept de “Campus as a Living Lab” uitgewerkt, geoperationaliseerd en in de praktijk geïmplementeerd worden?
- Wat is de volledige koolstofvoetafdruk van de Technische Universiteit Delft, inclusief zowel directe als indirecte emissies?

Elk van de volgende hoofdstukken behandelt een specifieke deelvraag. De verkennende aard van de vragen komt tot uiting in de verschillende methoden die in de hoofdstukken worden toegepast. Het proefschrift begint met een intern onderzoek gericht op de Technische Universiteit Delft in de hoofdstukken 2 en 3, en breidt zich daarna uit in hoofdstukken 4 en 5. Deze bredere benadering omvat het bestuderen van andere campusvoorbeelden, het uitvoeren van een systematische literatuurreview en het betrekken van een internationale Community of Practice.

Onderzoeksresultaten

Hoofdstuk 2 kwantificeert de directe en indirecte koolstofuitstoot van de Technische Universiteit Delft om een basislijn vast te stellen voor reductiestrategieën richting klimaatneutraliteit. In eerdere studies werden de moeilijk te berekenen indirecte emissies uit de op- en nevenstromen vaak buiten beschouwing gelaten, wat leidde tot een gefragmenteerd beeld en onvergelijkbare resultaten. Dit hoofdstuk biedt een uitgebreide analyse met behulp van een procesanalyse en een economische input-output-analyse. De resultaten wijzen op de koolstof-hotspots van de universiteit, zoals onroerend goed en bouw, het gebruik van aardgas en aangeschafte apparatuur. Ongeveer 80 % van de emissies zijn indirect, wat het belang benadrukt van het integreren van deze emissies en van de betrokkenheid van stakeholders in de toeleveringsketen voor beter gerichte en effectievere reductiestrategieën. Naast het identificeren van de hotspots voor de Technische Universiteit Delft, vormen de resultaten een transparant referentiepunt voor andere universiteiten en dragen ze bij aan betere vergelijkbare resultaten. Dit hoofdstuk wijst ook op problemen in de berekeningsmethoden en suggereert dat toekomstig onderzoek beter geschikte methoden moet ontwikkelen.

Hoofdstuk 3 verkent de kansen en uitdagingen van campus living labs die betrokken zijn bij experimenten rondom de energietransitie. Ondanks hun toenemende populariteit is er nog veel onduidelijk over hun werkwijze en hun innovatiepotentieel. Onderzoek naar de inbedding van living labs binnen HOI's is beperkt en bevindt zich in een vroeg stadium, wat hun implementatie in een campuscontext bemoeilijkt. Dit hoofdstuk onderzoekt zes living labs op de campus van de Technische Universiteit Delft via semi-gestructureerde interviews met intra-organisatorische stakeholders, variërend van onderzoekers tot operationeel personeel. De resultaten tonen verschillende interne en externe uitdagingen van de living labs. Interne uitdagingen zijn onder meer de noodzaak van effectieve samenwerking tussen stakeholders, het betrekken van gebruikers vanaf het begin, en het waarborgen van een duidelijke structuur voor het living lab, samen met goed gecoördineerde administratie en effectieve governance. Externe uitdagingen hebben betrekking op de moeilijkheid om living labs in te bedden in de organisatorische structuur van de universiteit, hun coördinatie en toewijzing van middelen op universitair niveau, en spanningen tussen academische en operationele processen. Ondanks deze uitdagingen concluderen we dat een universiteitscampus een vruchtbare omgeving blijft voor living labs om samen te creëren en te innoveren. Door bewustzijn te creëren en inzicht te geven in de uitdagingen waarmee living labs in deze context worden geconfronteerd, kunnen toekomstige initiatieven beter worden gefaciliteerd, zodat hun potentieel om te innoveren en bij te dragen aan maatschappelijke uitdagingen sneller kan worden benut.

Hoofdstuk 4 kijkt verder dan individuele casussen en onderzoekt de factoren die campus living labs mogelijk maken, waarbij wordt ingespeeld op de groeiende behoefte aan kennis over het faciliteren van deze omgevingen. De meeste studies naar living labs blijven beperkt tot enkele casussen en contexten, waardoor hun resultaten moeilijk te generaliseren zijn. Dit hoofdstuk maakt gebruik van een systematische literatuurreview om een breder perspectief te bieden en factoren te identificeren die in verschillende HOI-contexten van toepassing zijn. Het benadrukt ook het belang van het rekening houden met de ontwikkelingsfasen van living labs en hun specifieke faciliteringsbehoeften door de relevantie van de factoren in deze fasen te onderzoeken. Zestien factoren worden gepresenteerd, waarbij een diepgaande analyse van de vijf meest relevante factoren plaatsvindt. Deze vijf vertegenwoordigen de kern van living labs: stakeholders en netwerken, coördinatie op organisatieniveau, een stimulerende werkcultuur, co-creatie en samenwerking, en geschikte methoden en praktijken voor living labs. Daarnaast wordt de relevantie van alle factoren tijdens de fasen van voorbereiding, start, waardecreatie en opschaling beoordeeld door een expertpanel. Hiervoor hebben we een mappingsessie ontwikkeld, die op zichzelf kan dienen als discussietool voor living lab deelnemers. Onze resultaten suggereren dat sommige factoren, zoals stakeholders & netwerk, leren, en gedeeld begrip, essentieel zijn gedurende alle fasen. Verder worden specifieke factoren als invloedrijker beschouwd in bepaalde fasen. De initiatiefase steunt op leiderschap, coördinatie, betrokkenheid van stakeholders, een stimulerende werkcultuur en financiering. De operationele fasen worden mogelijk gemaakt door gedeeld begrip, intern management, samenwerking tussen stakeholders, methodologische geschiktheid en evaluatie. De disseminatiefase richt zich op overdracht, opschaling, evaluatie, leren en het overbruggen van stakeholders en contexten. Deze inzichten dragen bij aan een beter begrip van de factoren die campus living labs mogelijk maken gedurende verschillende ontwikkelingsfasen, en bieden op maat gemaakte richtlijnen voor stakeholders, terwijl ze de aanpasbaarheid aan lokale contexten benadrukken. Hierdoor kunnen campus living labs beter in staat worden gesteld om effectief duurzame oplossingen te genereren.

De belangrijkste bevindingen uit hoofdstukken 3 en 4 benadrukken het belang van coördinatie, kennisuitwisseling en organisatorische inbedding van campus living labs. Toch is er nog steeds behoefte aan een volledig begrip van hun implicaties en de vereisten voor implementatie, vooral wanneer HOI's hun potentieel voor duurzame transformatie structureel willen benutten, voorbij losse initiatieven. Als reactie op deze oproepen baseert *Hoofdstuk 5* zich op inzichten uit een internationale Community of Practice, bestaande literatuur en drie universiteitscasussen, waarbij verschillende iteratieve aanpassings- en validatiecycli worden toegepast. Dit leidt tot de conceptualisering van de "Campus as a Living Lab", die verschilt van de gebruikelijke aanpak van individuele "Living Labs on Campus". De Campus als Living Lab is een geïntegreerde aanpak die synergieën, kennisuitwisseling en kruisbestuiving tussen verschillende campusinnovatie-initiatieven bevordert. De hele campus en organisatie fungeren als een living lab, een vruchtbare grond voor duurzame experimenten en innovatie. Dit hoofdstuk beschrijft het initiële ontwikkelingsproces en biedt een context-aanpasbare tool voor de lancering van de Campus als Living Lab. De voorbereidingsfase richt zich op het vaststellen van de voorwaarden door het analyseren van de huidige stand van zaken van living labs, innovatieprojecten, testomgevingen en experimenten op de campus, het beoordelen van kerncompetenties, het identificeren van belangrijke interne en externe actoren, het bespreken van waarden, het ontwikkelen van een strategisch kader en het schetsen van de potentiële impact van deze aanpak. De startfase omvat praktische stappen om de Campus als Living Lab binnen de organisatie te integreren, zoals het opzetten van governance-structuren, het toewijzen van rollen, mandaten en verantwoordelijkheden, het toewijzen van middelen, het ontwikkelen van succesindicatoren, het plannen van evaluatiecycli, het definiëren van tijdlijnen en het ontwikkelen van een financieel kader. Dit hoofdstuk verduidelijkt de verschillende benaderingen die HOI's kunnen volgen ten aanzien van living labs op hun campussen en ondersteunt hen bij het opzetten van de Campus als Living Lab, waarbij ze hun unieke positie benutten om duurzame transformatie te stimuleren.

Conclusies

Campus living labs zijn veelbelovende omgevingen voor het bevorderen van duurzame oplossingen. Het creëren van de juiste lokale voorwaarden voor hun succes vraagt echter inspanningen op zowel het interne niveau van het living lab als op organisatorisch niveau van de hogeronderwijsinstelling. Een eerste analyse van de bevindingen uit hoofdstukken 3 en 4 suggereert dat de vijf belangrijkste faciliterende factoren die in hoofdstuk 4 zijn geïdentificeerd, effectief alle uitdagingen kunnen aanpakken die in hoofdstuk 3 zijn beschreven. Dit onderstreept hun relevantie als eerste stap bij het aanpakken van zowel interne living lab-problemen als bredere contextuele kwesties. Toekomstig onderzoek zou deze verbanden kunnen onderzoeken en bevestigen. Bovendien leiden de bevindingen van dit werk tot verschillende aanbevelingen, waaronder het betrekken van relevante stakeholders vanaf het begin, het erkennen en aanpassen aan het unieke karakter van living labs (in vergelijking met traditionele projecten) binnen de organisatie, het structureel inbedden van campus living labs, het systematisch ontwikkelen van de Campus als Living Lab, en het bevorderen van leernetwerken tussen campusinitiatieven en andere HOI's die vergelijkbare benaderingen volgen.

Campus living labs kunnen bijdragen aan klimaatneutraliteit door grote emissiebronnen aan te pakken, zoals de gebouwde omgeving, energieverbruik en de ingebedde emissies van aangeschafte apparatuur en ICT. Om effectief te kunnen functioneren, is het cruciaal om organisatorische barrières te doorbreken en stakeholders in een vroeg stadium te betrekken. Meer dan enkel het implementeren van losse living labs op de campus, moeten HOI's deze labs volledig integreren in hun operationele, onderzoeks- en onderwijsstructuren om hun volledige potentieel, evenals dat van de campusomgeving, te benutten. Het transformeren van de campus in een living lab stimuleert een samenwerkend leernetwerk, versterkt innovatie en vergroot mogelijk de impact buiten de campus. Toekomstig onderzoek moet de langetermijneffectiviteit van campus living labs en de Campus als Living Lab evalueren in het bereiken van klimaatneutraliteit.

In de tussentijd hebben zich belangrijke veranderingen voorgedaan op de TU Delft. Deze omvatten het opnemen van scope 3-emissies in de jaarlijkse koolstofvoetafdrukrapporten en het opzetten van een governancekader voor campusinnovatie, wat de inzet van de universiteit voor duurzaamheid benadrukt. Deze inspanningen bieden een veelbelovende toekomst voor het potentieel van living labs om de voortgang richting klimaatneutraliteit te versnellen.

Door op maat gemaakte richtlijnen te bieden en het belang van lokale aanpassing te benadrukken, wil dit proefschrift het innovatiepotentieel van living labs binnen HOI-contexten benutten om duurzame transities te stimuleren. Dit proefschrift kan dienen als basis voor directe actie en moedigt een gezamenlijke, dynamische en iteratieve verdere ontwikkeling aan. Nu is het tijd voor actie.

Chapter 1

Introduction

“[Living labs] will help to facilitate a vibrant research campus where numerous stakeholders are involved in getting real results.”

“There was a lot of confusion, I must say, different types of understanding of what we’re doing [in the living lab] until today.”

Both quotes stem from interviews conducted as part of this research, capturing contrasting perspectives on living labs. On the one hand, there is excitement, motivation, and anticipation about the innovation potential of living labs. On the other hand, there is confusion and a lack of understanding, with the term “living lab” often used as a vague catch-all phrase—hard to grasp but increasingly used in research and practice.

At the outset of my research, I asked many people what they understood a living lab to be, and unsurprisingly, I received different answers from everyone. Digging deeper, I often encountered uncertainty. Soon, I felt I was dealing with a topic that glittered brightly on the outside but was fuzzy on the inside. This initial impression highlighted the challenge: without understanding how things function on the inside, fittingly facilitating these living labs so they can unfold their innovation potential becomes difficult. Therefore, building on existing research, a better understanding of the inside and outside of living labs is needed.

1.1 LIVING LABS – WHAT IS THE BUZZ ABOUT?

Living labs have emerged as a prominent concept in contemporary research and innovation settings, often promoted for real-world problem-solving and user-driven innovation. This section delves into the theoretical underpinnings of living labs to unravel their foundations and key principles. Further, the section focuses on living labs in a Higher Education Institution context.

1.1.1 Living labs – theoretical background

Today's complex societal challenges, such as mitigating climate change, cannot adequately be tackled by individual disciplines, thus defying single-discipline problem-solving approaches (Nature, 2015). Instead, they require transdisciplinary approaches that bridge academic and non-academic knowledge silos and the science-society divide. To that end, practice and experience-based knowledge need to be integrated (Alvargonzález, 2011; Klein, 2010). This integration is crucial in fostering open, collaborative innovations aimed at sustainable solutions

Open (collaborative) innovation takes the standpoint that successful innovation emerges from networks of actors rather than individuals or single organizations. It emphasizes the need to open previously closed innovation processes to collaborate with external actors and the wider network to share knowledge, ideas, and expertise (Chesbrough, 2003). This approach enriches and complements the diversity of knowledge among the partners, fills knowledge gaps, compensates and enforces their skills, and shares risks and costs (Kimpimäki et al., 2022), making it particularly suited for addressing complex sustainability challenges. Living labs exemplify these principles as transdisciplinary settings for open innovation.

Unlike typical scientific laboratories that experiment under strictly controlled and replicable conditions, living labs operate in real-world contexts (J. Evans & Karvonen, 2014). They aim to generate (sustainable) innovations for complex societal challenges through multi-stakeholder co-creation, notably integrating users in the innovation process (Greve et al., 2021; Hossain et al., 2019). Thus, living labs are (1) set in a physical setting where real-life events occur, as opposed to simulated or theoretical contexts, (2) integrate academic and non-academic knowledge and methods from multiple disciplines to address complex problems beyond the scope of any single discipline, (3) collaboratively generate value, solutions, or outcomes by (4) involving stakeholders from governmental entities, academia, businesses, and users to address societal challenges.

Leminen and Westerlund (2019) trace the emergence of the living labs movement in three phases. Until the early 2000s, living lab studies were dominated by U.S. scholars and mainly focused on observing real-life situations. Later, living labs began to integrate user activities more actively in these real-life contexts. Through research teams, the pioneers at the Nokia Corporation, and increased external funding, living labs spread in Europe, leading to the establishment of European-level living lab networks. Especially the European Network of Living Labs (ENoLL) in 2006 boosted the living lab movement through agenda-setting and professionalizing living labs. Today, living labs have developed from scattered initiatives to a global movement, expanding beyond previously mainly ICT-related contexts to include fields such as agriculture, healthcare, the built environment, circular economy, environmental policy, as well as social innovation and innovation management (Schuurman & Leminen, 2021). This evolution has made living labs a widespread phenomenon, gaining momentum in research and practice, evidenced by the rapid growth of the scholarly literature (Greve et al., 2021; Hong Huang & Thomas, 2021).

While Leminen and Westerlund (2019) focused on the historical and geographical spread and professionalization of living labs, Leminen et al. (2017) classify the evolution of living lab research into three generations. The first generation focused on living lab landscapes as real-life environments with integrated user and stakeholder activities. The second generation emphasized methods and methodologies as part of the innovation activities in these real-life environments. The third generation illustrates diverse forms of collaborative innovation, highlighting various stakeholders' critical involvement in platform-based innovation, particularly users. Schuurman (2015) further distinguished the complex layers of living labs into macro, meso, and micro levels, i.e., the living lab organizational level, the living lab project level, and the level of user and stakeholder interactions and activities. These layers integrate both open and user innovation paradigms, with a focus on the role and integration of users in the innovation process (Hossain et al., 2019).

Living lab research, once considered a niche phenomenon in the mainstream academic literature (Greve et al., 2021; Hong Huang & Thomas, 2021; McLoughlin et al., 2018), is now recognized as an established stream in the innovation management literature (Leminen et al., 2023; Schuurman & Leminen, 2021). The interdisciplinary nature of living labs encompasses diverse contexts and perspectives (Greve et al., 2020; McLoughlin et al., 2018), resulting in numerous definitions and types of living labs (Greve et al., 2020; Greve et al., 2021; McCrory et al., 2020).

For instance, different research avenues see living labs as (1) a system, an ecosystem, or a network where multiple stakeholders collaborate; (2) a combined approach integrating various methods and tools; (3) a context or an environment, focusing on real-life interactions; (4) a method, methodology, or approach, providing structured research frameworks; (5) a tool for the enhancement and implementation of public and user involvement, (6) a development project for products, services, and systems, (7) a business activity or operational mode, driving business innovation; and (8) an innovation management tool, guiding the innovation process (Leminen & Westerlund, 2016). These varied perspectives highlight living labs' adaptability to different needs and contexts and their potential impact on various aspects of innovation. This versatility enables living labs to address complex challenges holistically, engage a wide range of stakeholders, and support different kinds of innovations. The varied avenues underscore the importance of flexibility and adaptability in designing and implementing living labs but also show their inherent ambiguity.

Steen and van Bueren (2017) identified over seventy definitions of living labs, highlighting the lack of a single, clear-cut definition, and demonstrated the divergence between theoretical framings and practical applications of what constitutes a living lab. This diversity of perspectives makes it confusing and challenging to pinpoint an exact definition yet contributes to the significant growth of the term. Scholars have proceeded to describe living labs' core characteristics such as stakeholders, the role of users, participation, aim, duration, scale, openness, and context (Følstad, 2008; Hossain et al., 2019; Nyström et al., 2014; Steen & van Bueren, 2017; Stuckrath & Rosales Carreón, 2021; Veeckman et al., 2013). In their comprehensive literature review, Hossain et al. (2019) crystallized eight main characteristics: (1) Real-life environments (context), (2) stakeholders, (3) activities, (4) business models and networks, (5) methods, tools and approaches, (6) challenges, (7) outcomes, and (8) sustainability.

Despite significant growth of the living lab literature in recent years, with 80 % (as of 2021) of publications emerging since 2015 (Hong Huang & Thomas, 2021; Schuurman & Leminen, 2021), there remains a gap in understanding living labs' inner workings, effectiveness, and their impacts (Ballon et al., 2018; Paskaleva & Cooper, 2021; Schäpke et al., 2024; Schuurman et al., 2015). Recently, Leminen et al. (2023, p. 1) underscore again that "the core of living labs and their principles remain largely underexplored." Additionally, knowledge about the sustainability of living labs and their roles and contributions to sustainability transitions remains insufficient (McCrory et al., 2022; Schuurman & Leminen, 2021). To effectively leverage living labs as vehicles for sustainability transitions, further research into their internal workings, organizational and governance structures, effectiveness in fostering innovation, and their overall impacts on societal and environmental challenges is essential. Understanding the complexities of their internal organization and governance is essential for improving their collaborative processes and stakeholder engagement. Additionally, assessing their effectiveness in driving innovation and addressing societal challenges requires evaluating their outcomes and impacts over the long term. By addressing these research gaps, living labs can be better equipped to fulfill their potential as drivers for sustainable innovation and societal transformation.

1.1.2 Living labs in Higher Education Institution contexts

HEIs are places of innovation, knowledge creation, transfer, dissemination, and education. On their campuses, there is a high concentration and an immense variety of intellect, suitable infrastructure for experimentation, and knowledge and technology production (Cortese, 2003). HEIs are locally rooted organizations with a vast global network and thus have significant power and impact on influencing, stimulating, facilitating, and driving change on various levels (Trencher, Bai, et al., 2014). More than 21,000 HEIs have about 235 million students worldwide (International Association of Universities, 2023; UNESCO, 2023). Their number, size, and societal position translate into a high societal relevance with significant impact potential.

Historically, HEIs have traditionally developed in strongly specialized disciplines (Cortese, 2003; Ledford, 2015). However, addressing today's societal challenges requires transdisciplinary approaches and settings, not only transgressing disciplinary academic silos but also the science-society divide. This calls for integrating external knowledge and partnerships (J. Robinson, 2008; Trencher, Bai, et al., 2014). This integration is ongoing in many forms, and living labs are one of them to facilitate it, promoting collaboration between academia and society across sectors and disciplines (Lough, 2022). Lozano et al. (2013) describe HEIs as semi-open systems with the responsibility to engage with both their internal operations and external stakeholders beyond their physical boundaries. Through collaboration and co-creation, HEIs can create open environments that transgress their system boundaries, contributing to engaging in their third mission. Besides education and research, this third mission involves contributing to society and distributing knowledge to a broader public (Compagnucci et al., 2021; Göransson et al., 2022). Trencher, Yarime, et al. (2014) even argued that co-creation for sustainability could be considered another emerging mission.

Living labs can enhance the interaction of universities, practitioners, and municipalities through co-creation and knowledge dissemination (McCormick et al., 2013; J. Robinson, 2008). HEIs play a crucial role as inherent parts of living labs and are recognized as a distinct research topic in living lab literature (Westerlund, Leminen, & Rajahonka, 2018). Living labs offer opportunities for HEIs to leverage different stakeholders' expertise to encourage knowledge application and innovation (Verhoef et al., 2020). In turn, living labs can address HEIs' sustainability challenges and transitions on various levels, contributing to both organizational and societal changes (Leal Filho et al., 2022). They may affect HEI operations, contributing to transformative institutional change and anchoring sustainability (Purcell et al., 2019; Vargas et al., 2019), thereby making HEI objects of change. Additionally, they may impact local or regional contexts beyond HEI boundaries through their network and stakeholders, scaling efforts, and contributing to the Sustainable Development Goals (Cuesta-Claros et al., 2023; Martek et al., 2022; Purcell et al., 2019) and thus acting as agents of change.

Especially on-campus living labs have the potential to influence and reshape HEIs' role and practices on a more substantial level, also regarding external relations and knowledge co-creation, as they are integrated into HEIs' day-to-day operations (Nyborg et al., 2024). Here, on-campus living labs might transform the HEI organization from the inside by fundamentally integrating sustainability operationally and academically, which requires institutional culture change (König & Evans, 2013; Nyborg et al., 2024). By opening up campuses and their organizations to facilitate local co-creation through on-campus living labs, HEIs can engage in sustainable innovation and transitions across various scales, from local to global, while becoming organizational experiments themselves (Nyborg et al., 2024; Verhoef & Bossert, 2019). In short, living labs and HEIs mutually benefit each other. For HEIs, living labs are an opportunity to engage in open transdisciplinary experimentation, technology development, problem-solving, and innovation at the heart of their organizations, directly implementing research findings and combining the pillars of education, research, and operation. HEIs can reconfigure their ivory tower image through living labs by showcasing real-world impact, research relevance, leadership, participation, accessibility, and co-creation while simultaneously attracting funding (Z. P. Robinson et al., 2022).

At the same time, HEI campuses are predestined places for living labs, as many of their described core characteristics are present by default. This includes the presence of a variety of stakeholders and users, collaboration opportunities, (innovation) ecosystems, curious and driven communities, and a general experimentation and innovation mindset, fostering open innovation and learning (Leal Filho et al., 2019; Martek et al., 2022). Further, the campus infrastructure may be owned and managed independently, making experimentation here less complex. HEI campuses are often compared to small towns in scale and complexity, as well as in terms of facilities, various users, food outlets, infrastructure, housing, and up-and-downstream consumption and emissions. Therefore, by functioning as an intermediary space with a city-like character, they make suitable test locations for bigger transitions (Martek et al., 2022; Purcell et al., 2019; Z. P. Robinson et al., 2022). Thus, on-campus living labs have similarities with urban living labs[1]. High levels of uncertainty and unknowability (not knowing a project's outcome, or in our case, the living lab) are probably more easily tolerated here. On campus, living labs can also benefit from the closeness to state-of-the-art knowledge, research facilities, vast resources, and provision of a long-term space for experiments and innovations (Leal Filho et al., 2019; Martek et al., 2022). Altogether, this gives the impression that HEI campuses and living labs are a perfect match.

Even though HEIs may have a great capacity for hosting and facilitating constellations like living labs, they seem to miss out on using them to their full potential to support innovations that create social value. The lack of institutional investment in boundary-spanning engagements, like living labs, and the tensions between top-down bureaucratic structures and bottom-up hinder the full development of social innovations within HEI systems (Lough, 2022). At the same time, the characteristics that make HEIs an attractive place for living labs, such as their complex ecosystems, can also present challenges to their effective operation and innovation potential (Z. P. Robinson et al., 2022). HEIs are often considered to have rather traditional, inflexible, and rigorous organizational structures, characterized by high bureaucracy, and are perceived to be slow to implement change (Bauwens et al., 2023; Lough, 2022; Lozano et al., 2013; Rymarzak et al., 2022). However, living labs' core characteristics embrace unpredictability, uncertainty, unknowability, failure, learning, and giving up complete project control, which clashes with these HEI structures. As they work in more open and collaborative

1 Urban living labs use cities as learning environments for innovations and aim to increase urban sustainability across different topics, like climate change, energy transition, transportation, and food systems (Bulkeley et al. (2016); Nevens et al. (2013); Rodrigues & Franco (2018); Steen & van Bueren (2017); Voytenko et al. (2016)). The similarities of the addressed issues in urban and campus living labs and the often close relationships of cities and HEIs that are sometimes even part of a city enforce that comparison. For instance, Schliwa and McCormick (2016) place the campus between a district and the city on a geographical scale.

network structures, living labs often might need to break implicit and explicit HEI norms and rules (Bauwens et al., 2023; Du Preez et al., 2022; Ventura et al., 2020). Therefore, living labs remain relatively unique in the traditional HEI governance. Their principles – transdisciplinarity, multi-stakeholder collaboration, citizen and user involvement, and co-creation – seem difficult to integrate into these prevailing structures (Tercanli & Jongbloed, 2022).

The previously mentioned knowledge gaps of living labs' inner workings, effectiveness, and impact might be increased in HEI contexts, as research into the embeddedness of living labs is limited and at an early stage (Tercanli & Jongbloed, 2022; van den Heuvel et al., 2021). Considering the ambiguity of multi-stakeholder goals, expectations, benefits, and challenges in living labs (Nguyen & Marques, 2022), there is an opportunity to improve understanding of living labs' inner workings in HEI contexts, as various stakeholders might be intra-organizational. Schliwa and McCormick (2016) distinguish between users and citizens in living labs, which becomes evident in campus contexts; here, often, the user might not be a citizen but the HEI or an HEI entity itself.

There is a general call for developing a common understanding and guidelines for living labs (Hong Huang & Thomas, 2021), including campus living labs. Existing insights into campus living labs are fragmented and limited, prompting scholars to emphasize the need for research on effective governance and coordination structures, implementation guidelines, understanding process phases, and campus living labs' wider impacts (Burbridge & Morrison, 2021; Martek et al., 2022; Z. P. Robinson et al., 2022; Save et al., 2021; Sker & Floricic, 2020). Effective governance and coordination structures are crucial to align diverse stakeholders and ensure seamless collaboration and organizational embeddedness in the HEI, while implementation guidelines can provide an approach for setting up and managing campus living labs efficiently. Understanding process phases is essential to navigating the complex development stages of living labs and facilitating tailored support to achieve their aims. Assessing wider impacts is necessary to determine the broader contributions of campus living labs to sustainability and innovation, justifying their value and guiding future improvements. By gaining insights into these critical issues, campus living labs' facilitation can be enhanced, and their potential to drive the sustainability transition can be better leveraged, both generally and within HEIs. This approach can maximize HEIs' as impactful contributors to substantial, sustainable change.

1.2 CLIMATE-NEUTRAL CAMPUSES

"The evidence is clear: the time for action is now" (IPCC, 2022, p. 1), proclaims the UN's Intergovernmental Panel on Climate Change (IPCC), since the following years are critical in tackling and mitigating climate change. Today's environmental and societal challenges, like climate change, have and will immensely impact humanity (IPCC, 2023). To limit global warming to 1.5 degrees Celsius, the key strategy is to avoid and reduce greenhouse gas emissions drastically (see Figure 1-1). Following is the need for an unprecedented, coordinated global effort to decarbonize, reach net-zero CO_2 emission around mid-century, and remove it from the atmosphere.

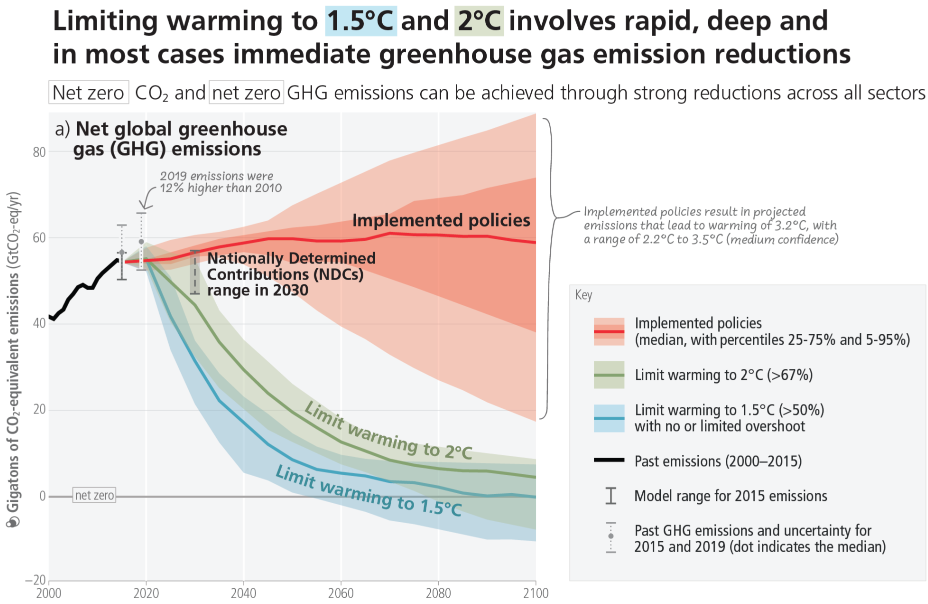

Figure 1-1: Pathways to limit global warming by reducing greenhouse gas emissions (IPCC, 2023, p.22)

Climate change is a topic that international organizations, governments, and societies throughout the globe currently address. Climate action, vital for sustainable development, must be accelerated across all sectors to adapt to and mitigate climate change (IPCC, 2023). This includes the Higher Education sector as well. Behavior changes, new technology, and innovations are necessary for those actions and transitions to happen shortly, amongst other interventions with already available knowledge. For the first time, the IPCC dedicated a separate chapter to "Innovation, Technology Development and Transfer" in its assessment report. This emphasizes its importance and identifies accelerated innovation as a key enabler in fighting climate change. Simultaneously, "rapid and far-reaching" transitions across sectors and improved innovation cooperation need to occur (IPCC, 2023). As knowledge institutions and drivers for innovation and change, HEIs can be vital in accelerating those transitions. In that, they have a double role. As mentioned before, they can function as change agents and objects of change. They can create a more sustainable future by facilitating transdisciplinary approaches and bridging the theory-practice divide (Lozano et al., 2013).

HEIs play a vital role in achieving the UN's Agenda 2030 for Sustainable Development (Parr et al., 2022). In that, they have the power to contribute substantially to the 17 Sustainable Development Goals by, e.g., engaging with their broad stakeholder network: Faculty, students, staff, alums, connected communities, companies, and their (innovation) ecosystems (Cuesta-Claros et al., 2023; Leal Filho et al., 2023). As such, HEIs can be understood as critical cases and subsystems within broader societal and environmental systems (Lozano et al., 2013). By assuming a societal role model function, they can demonstrate the feasibility of transitions, such as the energy transition, while integrating sustainability into their organizations.

Linking those broader sustainability challenges to local actions, HEIs worldwide have set up sustainable transition strategies and action plans, often aiming for climate neutrality in the coming decades (2030-2050). Almost 1.200 colleges and universities worldwide (as of December 2023) have signed up to commit to the global initiative "Race to zero", which seeks to mobilize leadership and action in the education sector (EAUC, Second Nature and UN Environment Programme, 2023). The signed HEIs commit to the goal of net-zero GHG emissions as soon as possible and by 2050 at the latest. Although this shows their commitment to becoming objects of change, those pledges have to result in organizational changes within HEIs that call for different ways of collaborating and operating. In contrast to these well-communicated sustainability aims and strategies, studies show that HEIs grapple with integrating sustainability holistically into their own organizations (Adams et al., 2018; Leal Filho et al., 2019). These struggles may concern, e.g., the lack of budget, insufficient staff capacity, deficient authority support, and the complexity of administrative procedures within the university (Vargas et al., 2019).

1.3 EXAMPLE – THE DELFT UNIVERSITY OF TECHNOLOGY

The topics mentioned above, climate neutrality and living labs, come together at the Delft University of Technology (TU Delft). For once, the university aims to become climate neutral by 2030, as stated in its Strategic Framework (TU Delft, 2018b, 2024b). Subsequently, there will be far-reaching changes in the university's operation and organization where innovative approaches play an important role. For that, the university states in its comprehensive sustainability vision, ambition, and action report that "using the campus as one large laboratory is expected to speed up the experimentation, evaluation, and implementation of new solutions that contribute to the sustainable development goals" (van den Dobbelsteen & van Gameren, 2021, p. 52). The Executive Board decided in November 2022 to invest 100 million euros in executing its plans to increase campus sustainability. A significant part of the budget (20 million euros) was initially reserved for facilitating future innovations and living labs (to be developed) (TU Delft, 2022c).

A recently established innovation board involving academics, operational staff, and students is now supporting campus innovations through a campus innovation process and providing funding opportunities, space, and governance. Currently, the focus is on innovations in the demonstration phases (Technological Readiness Levels 6–7), which have outgrown traditional and field labs on campus and are ready for testing in a campus environment before further scale-up. A TU Delft researcher should lead the innovation proposal with the encouragement of third-party involvement (TU Delft, 2024a). The focus may shift as governance structures, decision-making processes, risk assessments, legal questions, and other criteria around the TU Delft campus as a living lab are refined. An essential development is the initial draft of a mission statement for the campus as a living lab, co-created through a workshop and iteratively drafted by operation and academic staff involved in research and practice around the campus, innovation, and living labs[2]: *"At TU Delft, our vision is 'impact for a better society.' We achieve this by harnessing our campus as a living lab, where sustainability, user involvement, and co-creation are guiding principles. By fostering an environment open to testing innovations and actively engaging our community, we use our campus to create meaningful societal impact." (S. Boersma & A. Herth, personal communication, October 23, 2023)*

2 For transparency, I was involved in both the workshop and drafting the mission statement.

Even though the university's strategic aims and tactical and operational approaches mark steps in the right direction, there is still a need for further clarification in terms of definition, shared understanding, and focus.

1.4 PROBLEM, RESEARCH AIM, AND DEPARTURE POINTS

As outlined in the previous sections, there is an unprecedented need for sustainability transitions across all sectors to mitigate climate change and reach the net-zero greenhouse gas emissions goal. This not only includes emission avoidance and reductions but also the need for (social) innovation. Even though the aim might seem straightforward, solutions are complex, with multiple stakeholders, tradeoffs, and interconnected consequences. Tackling these complex societal questions, therefore, requires transdisciplinary approaches. One such transdisciplinary innovation approach is living labs. For example, Voytenko et al. (2016) have shown how living labs can play a role in the energy transition towards low-carbon cities. However, there is still a lack of knowledge about living labs' inner workings and operationalizations, their effectiveness in promoting innovation, and their overall impacts on societal and environmental challenges.

HEIs play a vital role in sustainability transitions by generating and disseminating knowledge and acting as agents of change. They can also become objects of change, illustrating sustainable transitions within their own organizations. Living labs enable HEIs to engage in both roles by implementing the knowledge and innovation they generate while integrating and engaging other stakeholders. Although campuses appear exceptionally well-suited environments for living labs, HEIs' organizational structures currently make it challenging to integrate them seamlessly. Furthermore, the specificities of the HEI campus setting and how campus living labs can contribute to HEIs' sustainability transitions are understudied. This gap makes it difficult for HEIs to create suitable conditions and maneuvering space for campus living labs, ultimately affecting their contribution to energy transitions to carbon neutrality. Consequently, various problem areas arise.

Firstly, HEIs often lack complete clarity on their direct and indirect carbon emissions, particularly those from up- and downstream activities (like procured goods and services, commuting, and business flights). These insights are essential for targeted and impactful emission reduction actions. Secondly, while campus living labs can be harnessed for the energy transition on and off campus, there is a need to better understand how to facilitate them effectively. This includes understanding their inner workings and organizational implementation to leverage the potential of both the HEI context and the living labs. An integrated approach to establishing a breeding ground, considering the whole campus as a living lab, is promising, but its conceptualization, operationalization, and concrete implementation guidelines are still lacking. By gaining insights into these issues, HEIs can be supported in creating suitable conditions for campus living labs and the campus as a living lab to flourish, unfold their innovation potential, and contribute effectively to climate neutrality and other sustainable transitions.

Against this background, **this dissertation aims to understand how campus living labs can contribute to the transition toward climate neutrality**. The research addresses the following four sub-questions, focusing on examining challenges faced by campus living lab participants from an intra-organizational perspective, identifying enabling factors for campus living labs across different development phases, exploring the concept of the Campus as a Living Lab, and pinpointing impactful focus areas for campus innovations by analyzing TU Delft's carbon footprint and emission hotspots.

- What challenges are encountered by participants in on-campus living labs, particularly from the intra-organizational HEI perspective?
- Which factors enable the well-functioning of on-campus living labs, and how do they vary in significance throughout living labs' different phases of development?
- How can the "Campus as a Living Lab" be conceptualized, operationalized, and practically implemented?
- What is the complete carbon footprint in the case of the Delft University of Technology, including both direct and indirect emissions?

A mixed-method research design addresses that aim by integrating both quantitative and qualitative methods (Creswell, 2014). This aligns with the interdisciplinary and explorative aim of this thesis. To answer the first sub-question, the carbon emissions of TU Delft are quantified. Subsequently, qualitative studies investigate the current situation of living labs on campus, including their challenges and enabling factors, and the different concepts of living labs in an HEI context to harness campus living labs' potential.

The studies in this thesis, as well as the thesis in its entirety, depart from certain understandings, made explicit in the following.

- Hopefully, by now, it is clear that the title of this dissertation implies a double meaning, namely, pointing to the two problem fields of this work—the contributions of campus living labs to sustainability transitions and their own transitions. The latter involves the need for a better understanding and facilitation of these settings so that the current “uncontrolled growth” can be developed into an impactful tool to be applied.
- Living labs are defined as “co-creation ecosystems for human-centric research and innovation. (…) [T]hey are physical regions or virtual realities where stakeholders form public-private-people partnerships (4Ps) of firms, public agencies, universities, institutes, and users all collaborating for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts” (Westerlund & Leminen, 2011, p. 20).
- Further, living labs are understood as a means to an end, namely the sustainability transition. Even more specifically, they are studied in regard to contributing to the energy transition.
- Living labs are studied under the premise that they have the potential to successfully innovate and contribute to the energy transition, as shown by previous scholars.
- The campus and the HEI environment are suitable test places for the broader sustainability of cities (J. Evans et al., 2015). The campus environment is seen as an ideal intermediary space and testing ground for experiments and innovations essential for broader urban sustainability transitions. The operation of a campus can be described as less complex than a city. However, it provides smaller-sized but comparable conditions regarding, e.g., infrastructure, various stakeholders and users, and public space.
- The rather unique high concentration of living labs in one campus location, operating under the same (local) contextual conditions, and the involvement of several intra-organizational stakeholders make campus living labs a valuable and accessible research subject.

1.5 SCOPE AND DISSERTATION OUTLINE

Departing from investigating the carbon footprint to establish the carbon hotspots of the university in Chapter 2, Chapters 3 and 4 zoom in on the inner workings of campus living labs. They aim to decipher what aids their facilitation on campus to ensure their well-functioning from two perspectives: campus living labs' challenges and enabling factors. Therefore, they are presented in the lighter blue frame and next to each other in Figure 1-2. Lastly, Chapter 5 consolidates the learnings of Chapters 3 and 4 while shifting the lens back to the level of HEIs by aiming at conceptualizing the campus as a living lab along with its organizational integration. Thus, while Chapters 3 and 4 specifically focus on on-campus living labs, Chapters 2 and 5 focus on the broader HEI context.

Methodically, Chapters 2 and 3 dive into case studies to investigate the current situation in depth, while Chapters 4 and 5 widen the perspective beyond case studies in a more overarching manner. Together, all chapters and their distinct perspectives contribute to reaching the research aim mentioned above. In the following, the content of the chapters is presented briefly. To get an overview of the chapters and their connection, refer to Figure 1-2.

Chapter 2 presents a comprehensive HEI carbon footprint, including both direct and indirect carbon emissions. Using the case of TU Delft, HEIs' carbon footprint and accounting practices are extended by integrating the often omitted indirect scope 3 emissions. In the study, a hybrid calculation method, including both process and economic input-output analysis, was applied. The chapter presents the carbon emission hotspots and leverage points for high reduction potentials toward carbon neutrality. Ideally, these hotspots could also be used as guidance for impactful experimentation and innovation areas.

Chapter 3 investigates on-campus living lab opportunities and challenges from an intra-organizational HEI perspective. The case of TU Delft is used once more for an in-depth analysis. Semi-structured interviews with internal operations and research participants were conducted to gain insights. By applying the knowledge gained, HEIs can better facilitate living labs and create living lab-friendly environments to harness their innovation potential.

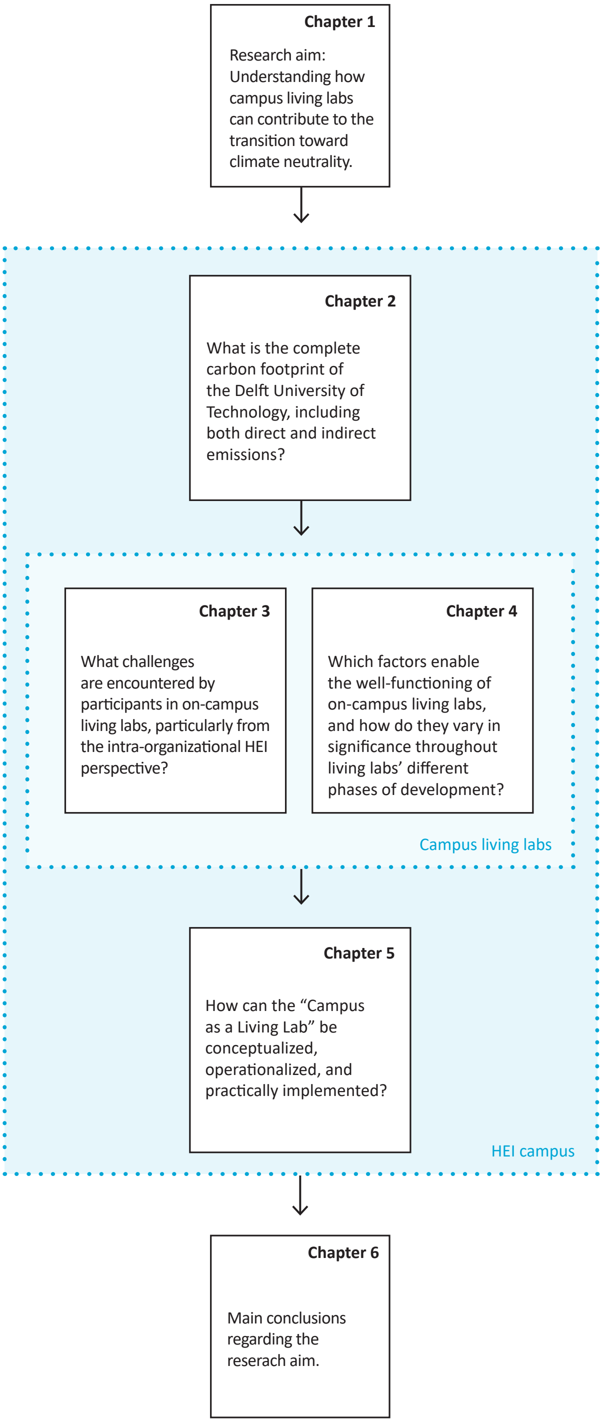

Figure 1-2: Overview and outline of the chapters

Chapter 4 complements the insights of Chapter 3 by investigating enabling factors for on-campus living labs' well-functioning. Removing the challenges presented in Chapter 3 might not automatically lead to living labs flourishing on campus. To that end, an extensive systematic literature review was conducted to distill enabling factors across the literature and cases. The chapter further establishes the factors' salience across campus living labs' development phases by consulting an international expert panel. The findings contribute to a better understanding of campus living labs' inner workings and contextual requirements while integrating their development phase-specific needs. The chapter offers guidance for stakeholders and HEIs to create the conditions for campus living labs to flourish.

Chapter 5 strives to conceptualize the "Campus as a Living Lab" in contrast to "Living Labs on Campus." Further, the chapter outlines the process stages and offers a context-adaptable tool to support HEIs in launching the Campus as a Living Lab. Drawing on the knowledge gained in Chapters 3 and 4, the chapter applies an iterative methodology involving insights from an international Community of Practice, academic literature, and experiences from three HEI cases. The chapter presents an approach to a strategic governance platform to institutionalize living labs in HEIs and to utilize their unique positions to contribute to sustainable transitions.

Chapter 6 concludes the findings of this dissertation by discussing its implications and recommendations from two perspectives, namely the perspective of campus living labs and HEIs. Further, it presents future research avenues based on this work. This thesis contributes to the sustainability transition and living lab theory by offering the unique perspective of campus living labs. The knowledge gained in this thesis might enable living labs in, across, and beyond HEI contexts to innovate, aiming at climate change mitigation and adaptation.

Higher Education Institutions play a vital role in educating about and researching climate change. However, they also need to take up climate action and implement climate policies within their organizations. Before addressing their own emission hotspots, they need to know about their carbon footprints first. Research on the carbon footprints of Higher Education Institutions has shown a scattered picture, particularly regarding indirect emissions from up- and downstream activities like construction on campus, ICT, equipment, and commuting. These are often disregarded due to insufficient data and unclear or missing calculation standards. In this chapter, we aim to close that gap by presenting a comprehensive analysis of Delft University of Technology's carbon footprint, including both direct and indirect emissions. With that, we contribute to an enhanced understanding of the university's carbon hotspots and enable targeted reduction strategies to achieve carbon neutrality within the next decade. We also provide a transparent reference for other Higher Education Institutions and highlight critical issues in carbon calculation methods.

Chapter 2

Quantifying universities' direct and indirect carbon emissions

The case of Delft University of Technology

A previous version of this chapter was published as:
Herth and Blok (2023). Quantifying universities' direct and indirect carbon emissions – the case of Delft University of Technology. International Journal of Sustainability in Higher Education, 24(9), 21–52. https://doi.org/10.1108/IJSHE-04-2022-0121

Spelling and formatting have been aligned throughout the dissertation.

ABSTRACT

This paper presents a comprehensive analysis of the carbon footprint of the Delft University of Technology (TU Delft), including direct and indirect emissions from utilities, logistics, and purchases, as well as a discussion about the commonly used method. Emissions are presented in three scopes (scope 1 reports direct process emissions, scope 2 reports emissions from purchased energy, and scope 3 reports indirect emissions from up- and downstream activities) to identify carbon emission hotspots within the university's operations. The carbon footprint was calculated using physical and monetary activity data, applying a process and economic input-output (EIO) analysis. TU Delft's total carbon footprint in 2018 is calculated at 106 ktCO_2eq. About 80 % are indirect (scope 3) emissions, which aligns with other studies. Emissions from Real estate and construction, Natural gas, Equipment, ICT, and Facility services accounted for about 64 % of the total footprint, whereas Electricity, Water and waste-related carbon emissions were negligible. These findings highlight the need to reduce universities' supply chain emissions. A better understanding of carbon footprint hotspots can facilitate strategies to reduce emissions and finally achieve carbon neutrality. In contrast to other work, it is argued that using economic input-output models to calculate universities' carbon footprints is questionable, as they can provide only an initial estimation. Therefore, the development of better-suited methods is called for.

2.1 INTRODUCTION

Reducing anthropogenic greenhouse gas (GHG) emissions to net zero is the key strategy to limiting global warming to 1.5 °C in the next century (IPCC, 2018; Kennelly et al., 2019; UNFCCC, 2015). To this end, the EU aims to be climate neutral by 2050, meaning emitting net zero GHGs (European Commission, 2019; Government of the Netherlands, 2019). While climate change was long considered an issue governments and international organizations had to tackle, all kinds of organizations are now taking up the responsibility to implement climate actions and policies themselves (UNEP, 2015). Universities, in particular, carry climate responsibility for educating future society, fostering innovation, and demonstrating sustainable transitions themselves (Botero et al., 2017; Jain et al., 2017). For example, more than 1,000 universities and colleges worldwide officially committed to the UN's "Race to Zero" with the goal of net-zero carbon emissions by 2050 (UNEP, 2021). This goal requires universities to be supported by all entities: faculties, corporate offices, administration, staff, and students (Button, 2009).

Before engaging in carbon dioxide emission reduction strategies, organizations must assess their current carbon emissions to consider options, impacts, and costs (Riddell et al., 2009). Carbon footprinting—assessing the carbon dioxide emissions of an organization and its supply chain—is gaining popularity as tools and standards are being developed to streamline the calculation process. The most popular standard that accounts for both direct and indirect GHG emissions is the GHG Protocol, which divides emissions into three scopes (1–3). Scope 1 accounts for direct emissions, such as combustion and process emissions; scope 2 accounts for those from the purchase of energy; and scope 3 accounts for all indirect up- and downstream activity emissions (World Business Council for Sustainable Development & World Resources Institute, 2004). Gaining insight into an organization's complete carbon footprint is vital to identifying emission sources and, thus, starting points for impactful reduction strategies.

Research into the carbon footprints of universities has revealed a diverse picture. Many higher education institutions (HEIs) voluntarily publish their carbon footprints (Udas et al., 2018). However, comparing them is difficult due to a lack of standards for HEIs and the variety of calculation methodologies, boundaries, functional units, inventories, and published emission factors (Helmers et al., 2021; Valls-Val & Bovea, 2021). Especially scope 3 emissions are often only partially accounted for. Nevertheless, results show that scope 3 emissions, if comprehensively included, are higher than scope 1 and 2. Therefore, investigating scope 3 emissions of universities is essential, as it unlocks an often unconsidered reduction potential. Hence, a standardized scope 3 approach considering all emission sources is important and called for (O. Robinson et al., 2015). O. J. Robinson et al. (2018) suggest a carbon footprinting standard for HEI, proposing two footprints. One comprehensive scope 1–3 footprint for internal carbon management use, and one scope 1–2 carbon footprint for external reporting. However, this impedes the publication of full-scale carbon footprints, which are often stated to be lacking.

Only very few universities present a carbon footprint also accounting for scope 3 emissions from university expenditures, for example, Yale University (Thurston & Eckelman, 2011), UC Berkeley (Doyle, 2012), De Montfort University (Ozawa-Meida et al., 2013), Norwegian University of Technology and Science (Larsen et al., 2013), Technical University of Madrid (School of Forestry Engineering) (Alvarez et al., 2014), and University of Castilla-La Mancha (Gómez et al., 2016). Emissions from expenditures account for a significant share in all studies, emphasizing the importance of including them in the carbon footprint of HEIs. However, here again, comparing those carbon footprints is difficult due to the variety of boundaries, methods used, and unpublished emission factors.

This study investigates and quantifies the direct and indirect carbon emissions of the Delft University of Technology (TU Delft) in 2018, including emissions from procurement and related emission factors. The aim is to present the university's complete carbon footprint to define starting points for reducing emissions since the university aims to achieve CO_2 neutrality by 2030 (TU Delft, 2018b). Furthermore, the authors reflect critically on current calculation methods based on this study's analysis.

To that end, a process and extended input-output life cycle analysis (EIOA–LCA) was applied for the consumption-based carbon footprint calculations. Whenever possible, physical activity data was used. This was the case for scope 1 and 2 emissions and business flights and commuting, for example. When physical activity data were not available, monetary activity data were used. For procurement and catering emissions, data based on economic input-output and hybrid multi-region methods were applied (Defra, 2014; Vringer et al., 2010).

This study contributes to the literature on carbon footprinting by expanding the scope of analysis to include previously often neglected activities, such as procurement. This expansion has three implications. First, it could facilitate the comparison of organizations' future carbon footprints. Second, it enables the identification of emission blind spots in organizational processes. Third, it calls again for developing HEI-specific carbon footprint guidelines.

2.2 THE CASE OF TU DELFT

2.2.1 The people and their campus
In 2018, TU Delft had 24,703 students and 5,421 full-time equivalent (FTE) employees. The number of students is expected to grow significantly in the years to come (28,000 students expected in 2026[3]).

The university campus is connected to the Dutch city of Delft and covers an area of about 161 hectares. It has 73 buildings with a gross internal area of 612,000 m^2. The university has eight faculties: Aerospace Engineering; Applied Sciences; Architecture and the Built Environment; Civil Engineering and Geosciences; Electrical Engineering, Mathematics and Computer Science; Industrial Design Engineering; Mechanical, Maritime and Materials Engineering; and Technology, Policy and Management.

The technical state of a significant share of buildings is reasonable or moderate, with an aging process that has started locally or is already affecting constructions and installations. This can be linked to the construction years of the university's buildings, many dating to the 1960s and 1970s. The challenge for the coming years is thus the need to renovate the campus (Blom & van den Dobbelsteen, 2019).

TU Delft operates its own heating and electricity grids. The combined heat and power plant (CHP) supplies almost all the heat demand on campus, using natural gas-fired reciprocating engines (a small proportion comes from installed gas boilers). The university plans to drill a geothermal source to provide the campus with heat in 2022. Besides the share produced by the CHP, all electricity is bought from renewable sources (wind farms) in the Netherlands. Today, the installed capacity of solar photovoltaic (PV) panels on campus is about 1 MW (TU Delft, 2018a). The university's main characteristics in numbers are shown in Table 2-1. The university's consumption of electricity, natural gas, water, waste generation, and travel data (business flights and commuting) are included in Table 2-2.

2.2.2 Sustainability strategy
The university stated its aim to become a climate-neutral and circular campus by 2030 in its strategic framework for 2018–24: "Develop and execute a sustainability plan for a CO_2 neutral and circular campus in 2030." (TU Delft, 2018b, p. 45).

3 The impact of the COVID-19 pandemic on student growth numbers is not considered here.

The university has recently taken several strategic decisions concerning the sustainability of its operations following this framework. Moreover, in 2019, TU Delft defined its position on Climate Action, which is one of the UN's Sustainable Development Goals: "TU Delft will harness its innovative powers to support the worldwide transition to non-fossil energy, and adaptation of the living environment to the consequences of global warming." (TU Delft, 2019b) To do so, the university will use its "intellectual and innovative power for safeguarding the world population against the risks of climate change, by developing technologies and methods …" (TU Delft, 2019b).

Table 2-1: Main characteristics of TU Delft in numbers

TU Delft 2018		
Campus area	ha	161
Gross internal area	m^2	612,000
Number of students		24,703
Number of staff	FTE	5,421
Spending	Euro	294,886,326

The Executive Board took another step by officially supporting the "Climate Letter" in 2019, as did all other Dutch universities (TU Delft, 2019a; VSNU, 2019). In the letter, scientists called on universities to reduce their carbon emissions by adopting and implementing ambitious climate agendas. Goals and measures should include reducing energy consumption, cutting back on flights, promoting sustainable modes of commuting, disinvesting in the fossil fuel industry, supporting environment-friendly food options, and reviewing educational offers concerning energy efficiency (Klimaatbrief Universiteiten, 2019).

In 2021, the vision, ambition, and action plan called "Sustainable TU Delft" was delivered to the Executive Board, comprising a comprehensive analysis of the current status, a lookout to the future, and steps to be taken to reach the sustainability ambitions of the university (van den Dobbelsteen & van Gameren, 2021). The report includes education, research, valorization and funding, community, and operations. For climate neutrality, key performance indicators for the campus buildings include reducing the university's overall energy consumption by 50 %, 50 % on-campus generation of electricity, and nearly 100 % self-generation of heat on campus by 2030. Furthermore, ambitious targets for new buildings and renovations address circularity, heat and electricity consumption, electricity generation, and carbon emissions in the building chain (Hänsch, 2020; Hänsch et al., 2020).

2.3 METHODS

2.3.1 Carbon accounting methods used

The emission scopes and sources were calculated according to the GHG Protocol of the World Business Council for Sustainable Development and World Resources Institute (2004). The choice of calculation method was influenced by data availability. When available, primary data in the form of physical activity and process data were used. This was the case for scopes 1 and 2, and for waste, business flights, water, and commuting data (scope 3). To calculate procurement and catering emissions, we used a top-down spend-based method that considered the economic value of services and goods purchased by the university. These methods will be further explained in the remainder of this section.

Calculations for all emission sources followed the same pattern. First, activity or consumption data were collected. The data are presented in, for example, kWh used, km traveled, kg generated, or euros spent. Second, specific, matching emission factors were derived from the literature to convert the data into GHG emissions. Emission factors indicate the amount of greenhouse gas emitted per data unit, for example, per liter of fuel or kWh consumed. They are presented in kilograms of CO_2 equivalents ($kgCO_2eq$) per unit. Then, the activity or consumption data were multiplied by the relevant emission factors to obtain the total CO_2eq emitted per emission source, which add up to the total carbon footprint (see Figure 2-1).

Emissions can be calculated in two ways. *Process analysis* maps all physical flows of a particular product throughout its life cycle. This enables the precise calculation of environmental impacts. However, obtaining the necessary data can be challenging and time-consuming, making the method expensive. In contrast to process analysis, *economic input-output models* (EIOs) describe an economy by mapping trades between economic sectors. All deliveries between the producer, trader, and consumer are shown in a matrix. These matrices facilitate quickly calculating a product's or service's environmental impacts along the whole supply chain in one specific sector. EIO tables, generally at the country level, allow for a fast overview; however, they are subject to a high level of aggregation (Kennelly et al., 2019; Thurston & Eckelman, 2011; Vringer et al., 2010). Hybrid models have been developed to combine the advantages of both models while avoiding their disadvantages. In those models, a process analysis is used for the primary process of a product's life cycle; for secondary processes, an input-output analysis is used (Vringer et al., 2010).

Primary data from various university departments for the year 2018 were collected: Electricity, natural gas, and water consumption data were provided by the Campus & Real Estate Department, flight data by the Human Resources Department, waste data by the Facility Management Department, and commuting data by the Education & Student Affairs and the Human Resources Departments. All are specific activity or process data derived from bills, meter readings, registrations, or purchase lists. For procurement and on-campus expenditures on food, financial data were obtained from the Finance Department and the university's caterer. In this case, emissions are expressed per economic value spent, thus, kgCO_2/€. Emission factors were derived from literature based on economic input-output models (Defra, 2014) and a hybrid multi-region model (HMR) (Vringer et al., 2010).

2.3.2 Emission sources

According to the GHG Protocol, all university-relevant emission sources were included in the carbon footprint calculation process to obtain a comprehensive overview of the carbon emissions. In general, no scopes or emission sources were excluded. However, relevant emission sources for the university (e.g., canteens and restaurants on campus) were added to scope 3, whereas irrelevant ones (e.g., sold products, their use, and end-of-life treatment) were disregarded. Figure 2-1 shows an overview of the calculation process and the emission sources considered in this study.

2.3.2.1 Data description of emission sources calculated with a process approach: Physical activity data and emission factors

Table 2-2 explains the origin of used input data and assumptions around them per emission source. Emission factors are described, and physical activity data from TU Delft for 2018 are shown. A description of the monetary-based input data and the process of adapting and matching emission factors to procurement-based emission categories are explained in more detail later.

2.3.2.2 Data description of emission sources calculated with an EIO approach: Monetary activity data and emission factors

Emission factor adaptation and matching process

The Finance Department provided monetary-based procurement data for 2018, comprising all goods and services procured by the university (ca. 1,400 entry points). The spend data were presented in three layers. *Category level 1* was divided into eight aggregated categories (i.e., person-related matter, office and operational means, transportation, and buildings and building-related installations and services). *Category level 2* provided more specific accounts.

Person-related matters, for example, contained 10 sub-categories on the second level. Examples are: Study, coaching, training and education; Business trips, external accommodation, catering; and Recruitment, selection and outplacement. The most detailed level was level 3, *“Description.”* The datasheet comprised 128 description titles at this level.

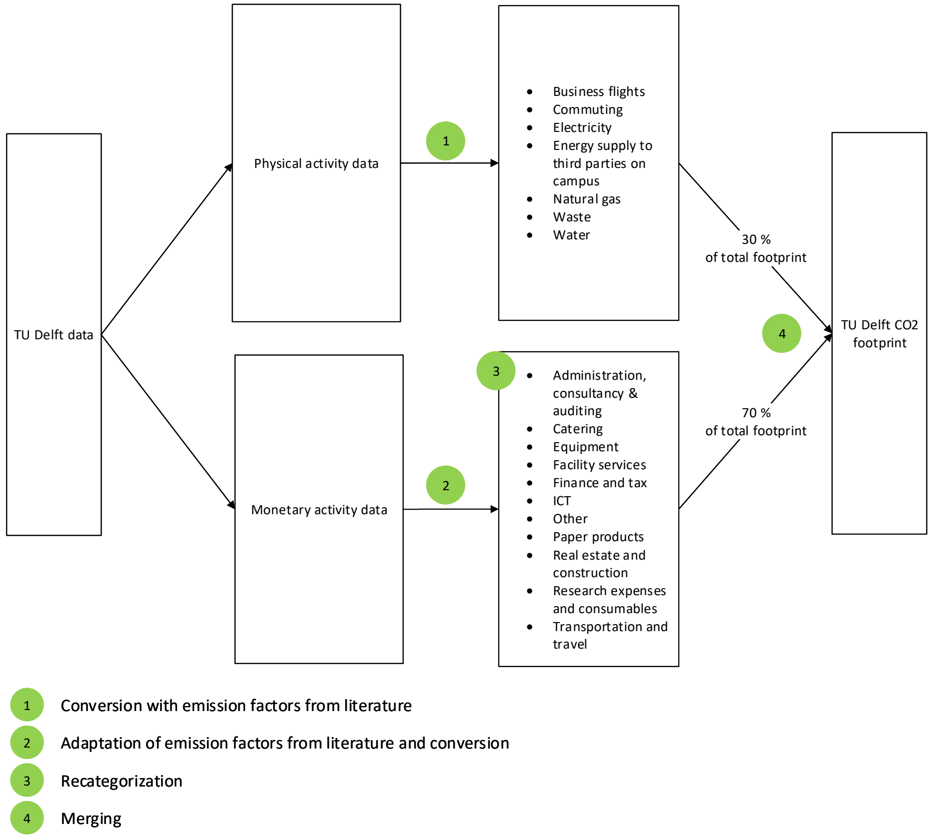

Figure 2-1: Overview of the calculation process

Table 2-2: Description of input data and emission factors of emission sources (physical activity data)

Scope	Emission source	Input data and assumptions
Scope 1	Natural gas	Obtained from the university's Energy team and TU Delft's Energy monitor website (TU Delft, 2018a). Data were divided into TU Delft's consumption and energy supply to third parties on campus.
Scope 2	Electricity	Obtained from the university's Energy team and TU Delft's Energy monitor website (TU Delft, 2018a). Data were divided into TU Delft's own consumption and the supply of energy to third parties on campus.
Scope 3	Business flights	Obtained from the university's travel agency.
Scope 3	Commuting by staff and students	According to an internal survey, 44 % of TU Delft employees cycle to campus, 32 % arrive by car, 17 % take public transport, and 5 % use carpools, e-bikes, motorbikes, scooters, or walk (van de Klugt et al., 2018). Forty percent of employees live in Delft. Those employees and those living up to 6 km from the campus are assumed to cycle or walk to work. In 2018, the average distance to campus was 14.5 km in a beeline, corrected by a factor of 1.2 to account for route detours (Blom & van den Dobbelsteen, 2019). It is estimated that 2.3 % of students arrive at the campus by car; the rest cycle or take a train. The average distance to campus for students was 16 km in a beeline, also corrected by a factor of 1.2. Blom and van den Dobbelsteen (2019) assume that employees travel to the campus 44 weeks per year, making 10 trips a week; students travel to campus 42 weeks a year, making eight trips per week.

Emissions factors	Activity and unit [x1000]
Well-to-wheel emission factors are used, including energy production and related processes, until the energy carrier gets to the point of use and the energy use itself. Emission factors from Milieu Centraal et al. (2018), yearly published and updated for the Netherlands.	9,271 m^3
Well-to-wheel emission factors from Milieu Centraal et al. (2018). The emission factor for electricity purchased from a wind farm is LCA-based. The same applies to the generation of electricity by PV panels.	53,644 kWh purchased
Emission factors comprise energy production and use and differ according to the flight distance: Regional flights (< 700 km), European flights (700–2,500 km), and Intercontinental flights (> 2,500 km). Moreover, a detour factor is included, considering that flights usually have to make detours before landing or due to weather conditions. Also, a radiative forcing factor of 2 is included, accounting for the climate effects of non-CO_2 GHGs at high altitudes. Emission factors from Milieu Centraal et al. (2018) and Otten et al. (2015).	33,333 passengerkm
The given shares of transportation modes and the corresponding emission factors were applied to the traveled kilometers. Based on the Dutch average, emission factors for fossil-fuel cars include the share of different car types (petrol, diesel, LPG, electric, and hybrids). Emission factors are well-to-wheel for all transportation modes and are taken from Milieu Centraal et al. (2018) and Stichting Stimular (2018).	Fossil fuel car: 16,946 vehiclekm Carpool: 830 passengerkm Motorcycle: 415 km Scooter: 415 km Train: 5,810 passengerkm Other public transport: 1,245 passengerkm Bike: 18,261 passengerkm Walk: 830 passengerkm

2

Table 2-2: Continued

Scope	Emission source	Input data and assumptions
Scope 3	Energy supply to third parties on campus	See Natural Gas and Electricity
Scope 3	Waste	Obtained from the Facility Management Department. Furthermore, the waste handling company, which includes avoided CO2 emission calculations in its annual reports for TU Delft, was approached. Fourteen waste streams are collected at TU Delft.[4]
Scope 3	Water	Obtained from the Energy team and through the Energy monitor website.

Emission factors were obtained from Vringer et al. (2010) and Defra (2014). Emission factors from Vringer et al. are based on a hybrid method model for households in the Netherlands, whereas Defra used an input-output model for the United Kingdom. Since both sources use historic (and different) base years, the emission factors were adjusted with a correction factor based on the GHG/GDP ratio for the European Union (EU 28) (European Environment Agency, 2020; Eurostat, 2022). This ratio was chosen to account for the decrease in the carbon emissions of products and services over time and inflation. Trading balances of the European Union show that most products and services were traded within the Union (Eurostat, 2021). The calculated GHG/GDP ratio resulted in static correction factors for the year 2018: 0.57 for the emission factors from Vringer et al. (2010) and 0.81 for emission factors from Defra (2014).

4 The 14 waste streams are: Residual waste; tires/rubber; construction and demolition waste; electric(al) waste; foil/plastics; hazardous waste; organic waste; glass; wood; coffee cups; paper and cardboard; rubble; swill; and confidential paper.

Emissions factors	Activity and unit [x1000]
See Natural Gas and Electricity	Natural gas: 1,873 m^3 Electricity: 14,669 kWh
Emission factors differ for each waste stream and its further processing: recycling, combustion, or landfill. After considering and comparing the waste company's emission factors with those in the literature (Turner et al., 2015), the authors decided to use the former as they matched exactly the 14 waste streams[4] and their specific processing and thus increased calculation precision. Emission factors include emissions from logistics and transportation, sorting, processing, and avoided production for recycling. For combustion, emission factors include emissions from logistics and transportation, processing, and avoided energy/products.	2,789 t
The energy input for the sewage plant and the distribution network are included in the emission factor from Pulselli et al. (2019).	167 m^3

The most detailed level (Level 3, Description) was considered to match specific emission factors to the spending (for the assigned emission factors, see Appendix A). Matching was done in four ways (see also Figure 2-2):

1. If there was a direct match between the description item and an emission factor, that emission factor was used.
2. If the description item matched different emission factors, the average of those was used.
3. If no matching emission factors were available for an item, the average of an emission factor group was used, e.g., an average emission factor of all hardware emission factors or service-related emission factors.
4. If none of the above-mentioned ways was possible, the average of all used emission factors was assigned to the remaining items.

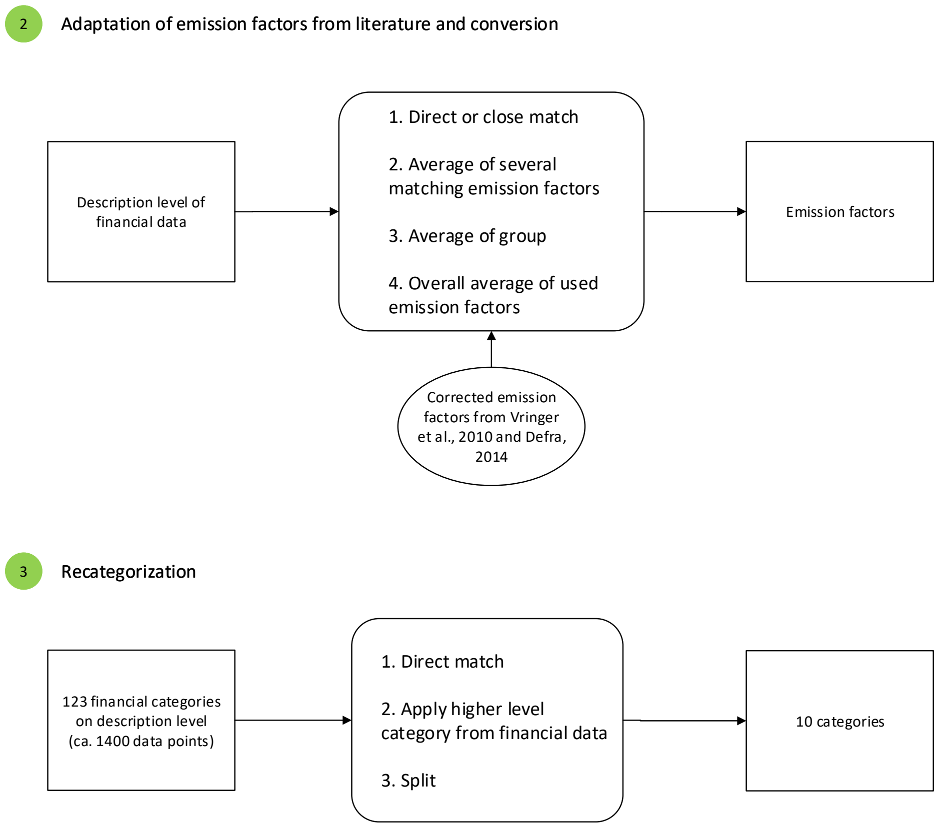

Figure 2-2: Matching of emission factors and recategorization of purchased goods and services, relating to steps 2 and 3 of Figure 2-1

Recategorization process of bookkeeping categories to carbon footprint categories

The description items were recategorized from bookkeeping categories to the carbon footprint emission sources explained in Table 2-3—reducing the category number from 128 to 10. Several description items were disregarded. Cost accounting items purely for accounting and bookkeeping purposes were excluded, as no action and thus no additional carbon emissions result from them. This was the case for depreciation items, received advance payments, and scholarships, for example. Items calculated separately based on physical activity data (electricity, natural gas, flights, water) were also deducted. Moreover, items considered the same for TU Delft and a third party (e.g., cooperation and collaboration with universities and guest lecturers) were disregarded to avoid the double-counting of emissions. Thus, it was assumed that TU Delft receives as many guest teachers and lecturers as it sends. Emissions are, therefore, already included in the scope 1 and 2 footprints.

Recategorization was done in three ways (see also Figure 2-2). In general, if one of the merged items within a description (originating from various category levels 1 and 2) contributed more than half of the financial sum of that description's total, the totality was assigned on that basis to one of the emission sources (see Table 2-3).

1. The description items could be directly matched with a specific carbon footprint emission source.
2. Description items were traced back to their original category 2 level to assign them to the carbon footprint emission source.
3. When there was no single significant contributor and too many category 2 level relations, items were assigned individually to a carbon footprint emission source.

Catering spend data from on-campus canteens and restaurants were obtained from the catering company and internally, comprising a list of sold food and beverage items. Emission factors are based on Vringer et al. (2010), corrected as described above. Meal ingredients were approximated to match the emission factors, as received data were based on meals sold, not ingredients.

Table 2-3: Monetary-based carbon footprint emission sources

Emission source	Activity data
Administration, consultancy, and auditing	Purchases and spending related to management costs, personnel, consultancy, and auditing costs
Catering	Spend data from canteens and restaurants on campus
Equipment	Purchases and spending related to scientific and other equipment, its maintenance, and the renting of equipment
Facility services	Purchases and spending related to office supplies, cleaning, furniture, its maintenance and renting, faculty catering, and disposal of environmentally unfriendly waste
Finance and tax	Banking costs, subsidies, tax expenses, and charges
ICT	Purchases of hard- and software, and audiovisual equipment, telephone costs, renting and maintenance of hard- and software
Other	Other indeterminable spending
Paper products	Purchases and spending related to books, and copying and printing costs
Real estate and construction	Purchases and spending related to buildings and the campus, technical installations and maintenance, rent of buildings, moving costs, replacements, construction, and general real estate services
Research expenses and consumables	Purchases and spending related to congresses and symposia, intellectual property, dissertations, and research consumables like gasses and chemicals
Transportation and travel	Spending related to travel and accommodation costs for employees, applicants, and third parties, as well as rent and maintenance of transportation means. Employees' flights and staff's and students' commuting are excluded and calculated separately (see Table 2-2).

2.4 RESULTS

2.4.1 Results obtained

The calculated consumption-based carbon footprint of TU Delft in 2018 is 106,000 tCO_2eq. Divided into the scopes of the GHG protocol, scopes 1 and 2 together account for 17 % of emissions, while scope 3 accounts for 83 % (see also Appendix A for a comprehensive table with the detailed calculations of all emission sources). This distribution is similar to results from other organizations and universities that included procured goods and services in their carbon footprint calculations; which again emphasizes the importance of including scope 3 in an organization's carbon emission reduction strategy and implementing practical reduction measures within that scope.

Figure 2-3 shows the breakdown of TU Delft's carbon footprint by scope and by emission source. Scope 3 emissions were divided into emissions influenced mainly by the university's operation (Real estate and construction; Equipment; ICT; Facility services; Research expenses and consumables; Administration, Consultancy & auditing; Transportation and travel; Energy supply to third parties on campus; Other; Paper products; Finance and tax; Water; Waste) and those mainly influenced by its staff and students (Business flights; Catering; Commuting). The vast majority of the total carbon emissions are scope 3 operation-related (69 %), while only a small part is related to staff and students (14%).

Real estate and construction is the most significant emitter (18 %), followed by *Natural gas* (17 %), *Equipment* (13 %), ICT (8 %), *Facility services* (8 %), *Business flights* (5 %), *Catering* (5 %), and *Research expenses and consumables* (5 %). The "big five" emission sources are responsible for 64 % of total carbon emissions. The eight emission sources contributing 5 % or more account for almost eighty percent of the total footprint. The remaining ten account for only 21 %. This highlights the need to address the most significant emission sources specifically. At the same time, the authors see the potential to significantly reduce the carbon footprint by focusing reduction strategies on the limited number of major emitters.

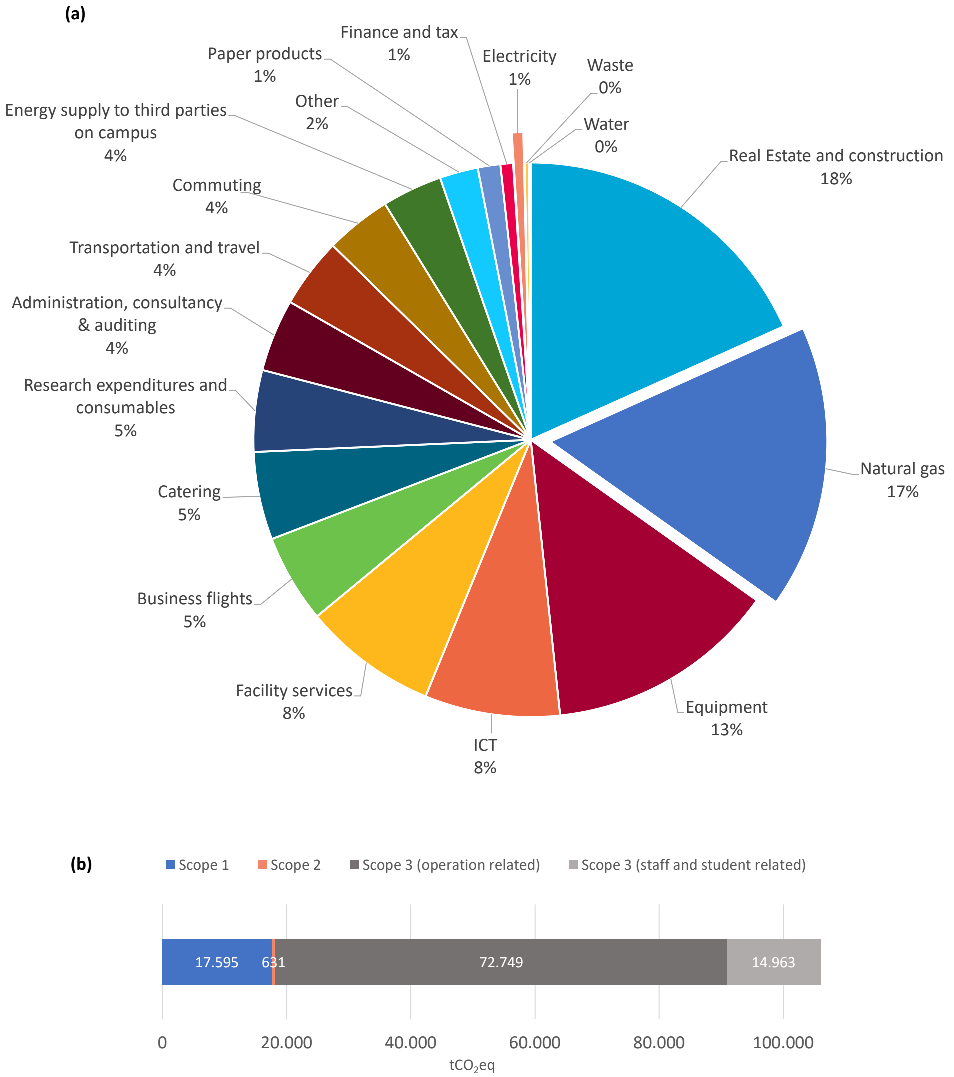

Figure 2-3: Total carbon emissions of TU Delft by (a) emission source and (b) scope (Scope 1: Natural gas and electricity generation PV; Scope 2: Purchased electricity; Scope 3: rest of emission sources)

2.4.2 Analysis of results

Some emission sources showing specificities concerning input data, their content, reduction plans, or potentials are discussed in more detail in this section since a framework for HEIs is missing.

Real estate and construction, the most significant emission source (18 %), includes many service costs with relatively low emission factors, such as guarding buildings, rent and leasehold, and daily maintenance. Although no major construction was carried out in 2018, the total emissions from the bookkeeping item "projects" account for almost 90 % of the total Real estate and construction emissions. Attempts to investigate what kind of projects this entails were challenging. So far, the authors have been unable to discover the specific content as would be desirable.

Regarding *Natural gas* emissions (17 %), TU Delft has decided to invest in a sustainable heat source, an on-campus geothermal well (TU Delft, 2022b). Consequently, natural gas emissions will drop. However, with the geothermal energy, formation gas will be extracted from the earth, which will count toward the carbon footprint. To provide a CO_2 neutral campus, the university must develop plans to deal with this issue.

Equipment is the third most important carbon emitter (13 %). It includes emissions from purchasing, maintaining, and renting equipment and technical items. About 75 % of the calculated emissions originate from the bookkeeping category "equipment." As with "projects" in *Real estate and construction*, the exact content of the description item "equipment" is not always entirely transparent.

Business flights were responsible for 5 % of the university's emissions. 70 % of flights were long-distance (>2,500 km). Short-distance flights (<700 km) contributed only 10 % of emissions. This means that a strict university regulation to justify the need for a flight will be a more effective reduction tool than the prohibition of business flights within a range of 700 km; for example, Schmidt (2022) discusses universities' air travel policies in detail.

Commuting by employees and students was another relatively small emission source (4 %). The Dutch are known for being a biking nation, which benefits the commuting footprint. Thus, the most reduction potential is seen in the 32 % of employees who currently come to the campus by car. TU Delft has set a 10 % reduction target for car commuting by 2025, compared to the base year of 2018 (van de Klugt et al., 2018).

Electricity accounts for only 1 % of TU Delft's carbon emissions, including life cycle emissions from installed PV and purchased wind energy; thus, emissions from different scopes are combined to show the complete picture. If the university had bought its electricity from the grid, it would have resulted in 34,139 tCO2eq, almost double the biggest emission source. Since the input for the CHP to generate electricity is natural gas, originating emissions are accounted for in *Natural gas*.

Surprisingly, although the authors expected the university to be a “paper organization” with a considerable amount of paper being bought and many books being produced and printed, emissions from *Paper products* play a negligible role in the overall footprint (1 %).

Finance and tax (1 %), *Waste* (0 %), and *Water* (0 %) are the emission sources with the least impact on the total footprint. However, this does not suggest that measures to reduce waste or increase waste sorting have no impact. Waste recycling can play a vital role in achieving carbon neutrality by closing material loops and avoiding embodied emissions. Additionally, waste should be investigated in relation to procured goods.

2.4.3 Uncertainty analysis

Knowing TU Delft’s carbon hotspots enables the university to develop reduction strategies that will have the biggest possible impact on the total footprint. However, the results are still at a high level of abstraction and subject to uncertainty.

The uncertainty of results is substantial for some emission sources—especially in the case of emissions calculated on a spend basis, which account for the most significant part of the footprint (70 %). Consequently, variations in those calculations will have a significant impact.

The uncertainty of the input data and that of the used emission factors were considered to assess the results’ uncertainty level, according to the IPCC and GHG Protocol guidelines (IPCC, 2000). Uncertainties were estimated by emission source and the IPCC error propagation equation was used to evaluate their impact on the results, as described in the following paragraphs.

Combined uncertainty levels were estimated to be high for emission sources calculated on a monetary basis, for Business flights, and Commuting of staff and students (± 30 % for most of them). For all emission sources calculated on a monetary basis, *activity data uncertainty* was considered 10 % due to recategorizations of bookkeeping categories and non-transparency of specific contents. Moreover, in 2018, the financial department’s accounting system was renewed, resulting in some inconsistencies in bookkeeping categories. An activity data uncertainty of 30 % was considered for Catering, Business flights, and Commuting. *Emission factor uncertainty* was estimated to be 30 % due to the correction of emission factors and their combination from different sources, often based on households. For Business flights, emission factor uncertainty was estimated at 20 % due to detours, non-European departure locations, emissions in great heights, and flight lengths. For Commuting, 10 % were estimated.

Waste (± 14 %), Electricity (± 10 %), and Energy supply to third parties on campus (± 10 %) are estimated to have moderate to low combined uncertainty levels from activity data and emission factor uncertainty. Natural gas and water are considered to have very low combined uncertainty levels (both ± 1 %).

The authors estimate the combined uncertainty levels of this study to be moderate. Repetition of the calculation with precisely the same input data would lead to another calculated amount of carbon emissions due to different data allocation and (sub-)categorization; however, the deviation is estimated to be about 10 %. Moreover, a significant shift in the order of contributing emission sources would not be expected. A previous study estimating TU Delft's carbon emissions from procurement in 2015 came to about the same results (Mauro, 2017). Additionally, the result is in line with the calculations of other universities. Despite the uncertainty, the result is thus considered robust.

Nevertheless, the authors see a need for better-investigated input data and more specific emission factors, especially for procurement. TU Delft has started submetering buildings to investigate electricity consumption patterns inside buildings and a project to better register suppliers and their environmental emissions. In addition, a framework defining boundaries for HEIs' scope 3 calculations (including the scope of the emission source itself) is needed to facilitate comparisons and benchmarking of carbon footprints in the sector.

2.5 DISCUSSION

2.5.1 Comparison of results with other universities

The most common comparison ratios relate the carbon footprint to the number of students and staff, the gross internal area of campus buildings, and the spending (Helmers et al., 2021; Valls-Val & Bovea, 2021). Compared to previous studies of universities, which included procurement emissions in their calculations, TU Delft's emission ratios generally align. However, there are some exceptions, as described below. Table 2-4 compares the carbon emissions of the mentioned studies per gross internal area, per person (staff and students), and euro spent.

TU Delft's footprint is 0.17 tCO_2eq/m^2, 19.54 tCO_2eq/FTE, 4.29 tCO_2eq/student, and thus 3.52 tCO_2eq/capita, and 0.44 $kgCO_2eq$/€ spent. Those numbers particularly align with the case of the Norwegian University of Technology and Science (Larsen et al., 2013). Previous studies have shown that social science faculties have a smaller footprint than their technical counterparts (Kulkarni, 2019; Larsen et al., 2013). Furthermore, Klein-Banai and Theis (2013) showed that laboratory spaces of research-intensive institutions affect the carbon footprint manifold more than offices, lecture halls, and classrooms. This might explain the emission rates of both universities. However, Helmers et al.'s (2021) comparisons do not confirm this. Furthermore, the high result per euro spent by Alvarez et al. (2014) is noteworthy, for which they reason in their study.

Table 2-4: Comparison of carbon emissions per gross internal area, per person, and per euro spent by different universities

University and country	**tCO_2eq/m^2**	**tCO_2eq/person**	**$kgCO_2eq$/€**	**Authors**
De Montfort University, GB	0.40	2.00	0.34	Ozawa-Meida et al. (2013)
Norwegian University of Technology and Science, NO	0.13	3.61	0.38	Larsen et al. (2013)
Delft University of Technology, NL	0.17	3.52	0.44	
Technical University of Madrid, School of Forestry Engineering, ES	0.07	1.55	2.81	Alvarez et al. (2014)

In Helmers et al.'s (2021) rankings, which did not include procurement emissions, TU Delft would be situated in the top ten of the least emitting universities in all three ratios. Procurement emissions from the TU Delft's carbon footprint were excluded from this comparison. Ranked by emission per capita, with 1.1 tCO_2eq/capita, TU Delft would come in the eighth or ninth-best place[5] (meaning least emitting) from then 23 HEIs. However, it would come in second place with 52 $kgCO_2eq/m^2$. Likewise, it would come in the second best place relating emissions to university expenditure (without salaries and purchasing power corrected), namely 90 $kgCO_2eq$/1000$. The good rankings might be explained by the fact that TU Delft exclusively buys green electricity (to which life cycle emissions were assigned), which reduces the carbon footprint significantly compared to other universities.

2.5.2 Assessment of calculation method

Calculating scope 3 emissions calls for the making of qualified boundary choices. It was chosen to integrate all emission sources to obtain a complete picture of the footprint, knowing that some uncertainty levels were elevated. Comprehensiveness versus accuracy is a debatable issue. Another point is boundary setting; that is, what to include in scope 3 emission sources without adding the emissions of whole supply chains and personal choices of employees and students to the university's account.

For example, many people working and studying at TU Delft come from abroad. Whereas business trips made on behalf of the university were included, trips to the home countries of staff and students were not. They were considered to be accounted for in personal carbon footprints. However, commuting was included in the university's carbon footprint, so where people lived did impact the footprint. Another example is calculated catering emissions. Food and beverages sold on campus were considered. It is debatable whether food brought from home should also be included in the footprint since people must eat to work. Since these boundaries impact the results, the examples show that it is not enough only to define which emission sources to include or exclude. It is essential to provide guidelines in a HEI framework defining where to draw boundaries within those emission sources to assure comparability, also stated by Ozawa-Meida et al. (2013) and Valls-Val and Bovea (2021).

Regarding the calculation method, estimating the footprint based on spending might result in wrong conclusions for several reasons. Sustainable suppliers, for example, might charge more. Choosing such a supplier will result in higher calculated emissions when, in reality, emissions might be reduced (Larsen et al.,

5 Due to the same ratio of three universities, the exact place could not be defined.

2013). Also, economy-of-scale-effects, which might be substantial for a university, are not included (Larsen et al., 2013; Alvarez et al., 2014). In addition, emission reductions occurring over life cycles will not appear in future spend-based carbon footprints. This is especially the case for the construction and renovation of buildings. Next, large investments in a specific year affect and distort the carbon footprint of that year since they are not spread over the lifetime. Thus, vast expenditures (like renovations or the purchase of large laboratory equipment, for example) will significantly increase calculated carbon emissions when, in reality, they might reduce scope 1 and 2 emissions in the future (Ozawa-Meida et al., 2013). However, allocating historic emissions over the years may not solve this problem, as it distorts the momentary picture and prevents perspectives for immediate actions. Therefore, future research is called to investigate and develop a method to deal with extensive investments to level out under- and overestimating carbon emissions.

Likewise, spend-based emission factors could result in over- or underestimating carbon emissions. For example, Vringer et al. (2010) based their emission factors on Dutch households. Using them for an institution like a university might distort the results due to a scale-up that the authors never intended, nor included in their calculations. Nevertheless, they are the most detailed and specific to the Dutch system and culture at the moment.

Concise calculation of procurement-related emission sources involves specifying and investigating each one in depth. This makes the calculation process time-consuming. Moreover, various people's commitment in different departments is needed to thoroughly analyze and interpret the financial data, its layers, and categories. The authors reached a point where they could not analyze the specific content of financial categories any further. Container terms like “projects,” “equipment,” and “technical items” did not convey what was included and led, even after consultations, to investigative dead ends. As other case studies also stated the necessity to interpret spending categories and the need for a more detailed uniform category breakdown (Ozawa-Meida et al., 2013; Alvarez et al., 2014), the general suitability of the calculation method used is questioned by the authors.

Calculating on a spending base depends on the accounting system's consistency in the long term. A change of systems or categorization will also affect the footprint calculations. Therefore, accounting systems should not be the base for monitoring carbon footprints over time. Ideally, procured goods' physical activity data should be available, i.e., material data stored in a material database. This aligns with the aim of a circular campus for which the university needs to know about its material stocks, in-, and outflows. Consequently, the carbon footprint could be calculated on a material base instead of a spending base, leading to more precision.

Another risk accompanying the chosen approach is the double-counting of avoided CO_2eq. First, avoided carbon emissions are included in the emission factor of waste streams. Second, avoided CO_2eq might be included in emission factors for products with a recycled material content. This would result in double-counting of the same avoided emissions. Therefore, organizations need to consider where avoided emissions are included to prevent whitewashing in upstream or downstream scope 3 calculations.

All other studies, which included procurement emissions, call for adjustments in the calculation methods. These include: Hybridization also for scope 3 emission sources (thus using a process approach); the development of a set of indicators for the most significant contributors calculated on an EIO basis (Larsen et al., 2013); a common reporting framework for HEI with defined organizational boundaries and a uniform breakdown of procurement categories, considering product carbon footprints of goods and services and LCAs of waste streams and recycled materials; monitoring embodied emissions and refurbishments (Ozawa-Meida et al., 2013); and the consideration of the geographic location, more recent IO data and economies of scale (Alvarez et al., 2014). Nevertheless, all consider their approach practical and applicable to other HEIs, which the authors of this study question for the reasons mentioned above.

2.6 CONCLUSION

The calculated direct and indirect carbon emissions of TU Delft were 106 ktCO_2eq in 2018. Eighty-three percent of the total footprint were scope 3 emissions, highlighting the need to consider organizations' up- and downstream activities to achieve carbon neutrality. This 20/80 distribution across the three scopes was also seen in other cases that included emissions from procurement. The five most significant emission sources (Real estate and construction, Natural gas, Equipment, ICT, and Facility services) were responsible for 64 % of the total carbon footprint. Efficient carbon emission-reducing strategies can, therefore, focus on these hotspots.

The authors see several limitations in this study. First, as in other studies, activity data lacked accuracy or had a high aggregation level. Second, the latter was also true for the emission factors from economic input-output and hybrid method models. Therefore, they cannot account for product differences, production processes, and recycled material content. The elevated uncertainty levels of some emission sources and the limitations of the calculation process imply several avenues for future research. The authors call to discuss and develop calculation methods that improve results' accuracy and precision. Those methods should clarify emission source boundaries and consider life cycle carbon emissions and reductions.

This study adds value by reviving the discussion about better-suited calculation approaches, including issues related to spend-based calculation methods; e.g., the difference between calculated and actual emissions for (eventually) pricier sustainable products or the increase of the footprint due to substantial investments, which however might lead to emission reductions in the long-term.

Real progress regarding these issues only seems possible when suppliers make their product's carbon footprint or material data available. Hence, calculating scope 3 emissions on a material or physical activity data basis would be possible, enabling more precise indirect carbon footprint calculations. Universities can then take up their role model function by including scope 3 emissions in their climate neutrality goals and lead the way in their realization to mitigate climate change.

In the previous chapter, we established focus areas for emission reductions. To achieve the goal of carbon neutrality, innovative solutions are essential. The campus naturally brings together many relevant stakeholders to tackle complex problems like climate change, providing long-term experimentation space and access to state-of-the-art knowledge. Additionally, the campus may provide long-term experimentation space and access to state-of-the-art knowledge. It appears to be an ideally suited space for complex experimentation and innovation settings that require multi-stakeholder involvement and real-life environments, such as living labs. Yet, little is known about living labs in campus settings and their operational dynamics. Therefore, this chapter uses the Delft University of Technology case study to investigate current opportunities and challenges of on-campus living labs. With the insights gained, future initiatives may be better designed and facilitated so that on-campus living labs can unlock their innovation potential for targeted solutions, contributing to a more sustainable campus and world.

Chapter 3

The innovation power of living labs to enable sustainability transitions

Challenges and opportunities of on-campus initiatives

A previous version of this chapter was accepted for publication as:
Herth, A., Verburg, R., & Blok, K. (in press) The Innovation Power of Living Labs to Enable Sustainability Transitions: Challenges and Opportunities of On-Campus Initiatives. *Creativity and Innovation Management*.

Spelling and formatting have been aligned throughout the dissertation.

ABSTRACT

Living labs are becoming increasingly popular as suitable arrangements for co-creation and innovation by bringing multiple stakeholders together to work on (solving) complex societal challenges. University campuses are ideal places for living labs, and many universities use such arrangements for various experiments in relation to sustainable future initiatives. Despite the popularity of the living lab concept, much remains unclear about their ways of operation and their potential to innovate. This study aims to show some of the current challenges of on-campus living labs involved with experiments concerning the energy transition. A total of six different living labs were examined based on semi-structured interviews with different stakeholders ranging from researchers to operational staff members. Our results show several internal and external challenges, such as the living lab setup and multiple operational challenges concerning administration, coordination, and governance. More external challenges include the overall embeddedness of living labs within the more traditional organizational structure of the university and the tensions between academic and operational staff. Despite these challenges, we conclude that a university campus is still a fruitful place for living labs to co-create and innovate. By creating awareness and understanding of the challenges living labs face, future initiatives may be facilitated better so that campus living labs are able to unlock their potential to innovate and contribute to societal challenges sooner rather than later.

3.1 INTRODUCTION

As institutions for knowledge creation, transfer, and innovation, universities play a vital role in enabling a more sustainable future (Cortese, 2003; Lozano et al., 2013). With their strong links to governments, citizen groups, industries, investors, businesses, and the younger generation, universities are ideal places to experiment and influence society by creating awareness in trying to become, for example, climate-neutral (Purcell et al., 2019). Besides research and education, the third mission of universities is to share their knowledge with a wider audience. However, according to Göransson et al. (2022), this is often translated into technical products rather than social innovation activities. Trencher, Yarime, et al. (2014) argue that universities need to engage in a new mission aimed at "co-creation for sustainability." To this end, universities need to engage in open, collaborative structures of various actors (Trencher, Bai, et al., 2014; Ventura et al., 2020). To do so, new approaches to transdisciplinary knowledge (co-)creation need to be incorporated into the current university activities (König, 2015).

Klooker and Hölzle (2023) focus on the creation and evolution of collaborative innovation spaces. They argue that both the creation process and the evaluation approach are vital for collaboration spaces as they evolve and change continuously over time. Collaborative innovation happens in an "in-between space" where actors can break free from organizational culture and experiment together. That illustrates the role of space and boundary objects in facilitating effective collaborative innovation, leveraging the affordances of convergence, generativity, socialization, and collaborative learning within innovation spaces (Caccamo, 2020; Yström & Agogué, 2020). This perspective is also relevant for living labs, where the influence of the physical space on the living lab, its organization, governance, and participants, plays a significant role (Della Santa et al., 2022). Perez Mengual et al. (2023) offer a taxonomy to facilitate the intentional design of innovation spaces, such as living labs, extending beyond physical layout to include value propositions for all stakeholders. This taxonomy aims to ensure that innovation spaces are purposeful and sustainable, emphasizing the need for clear design intentions from the outset. It covers the design of space, processes, actors, value propositions, and creation within the innovation space, guiding designers and participants towards clarity on key value propositions and related design implications, thereby enhancing operational effectiveness.

Not even ten years ago, living labs were still considered a rather new methodology with limited attention (Dell'Era & Landoni, 2014). Since then, the number of living labs has increased dramatically, sparking research and leading to a diverse and scattered body of knowledge (Greve et al., 2020; Hossain et al., 2019; Leminen & Westerlund, 2019). Living labs are co-creation settings where different stakeholders experiment, develop, test, validate, innovate, and learn together in real-world environments. Among a number of arrangements for co-creation and innovation, living labs are regarded as the most promising structure of partnership development along the university-industry-government nexus (Burbridge & Morrison, 2021).

University campuses are often regarded as favorable locations for living labs to foster open innovation by bringing a diverse group of stakeholders together for research, showcasing, and learning (Leal Filho et al., 2019; Martek et al., 2022). On a campus, living labs are close to extensive research facilities and may benefit from a culture of innovation and access to state-of-the-art knowledge. As many universities own large (campus) premises, the campuses may provide a long-term space for experiments and innovations when strategically coordinated with the campus development plans (Leal Filho et al., 2019).

On-campus living labs are particularly well suited for accelerating the sustainability transition as these labs can potentially affect the university's operations, including anchoring sustainability in its functioning (Vargas et al., 2019). Campus living labs may also have ample opportunities to impact the local environment beyond the campus (Martek et al., 2022; Purcell et al., 2019) by contributing to the United Nations 2030 Agenda for Sustainable Development with the 17 Sustainable Development Goals. For example, living labs can play a role in the energy transition towards low-carbon cities (Voytenko et al., 2016).

In that, university campuses may be considered intermediary spaces with a city-like character. Comprising controlled lab environments (micro-scale) and being part of the city (macro-scale), university campuses are suitable testbeds for bigger societal transitions (Martek et al., 2022; Purcell et al., 2019). The campus (including all its resources, infrastructure, and facilities) then becomes an innovation, teaching, and learning arena, improving the campus and university operations by translating sustainability concepts into tangible outcomes (Save et al., 2021). Westerlund et al. (2018) show that living lab research includes a number of different topics, such as design, cities, innovation, ecosystems, and universities. Universities, in particular, are often heavily involved with living labs and seen as a local force in driving societal impacts (Compagnucci et al., 2021).

Although the campus may seem like an ideal place for living labs with great potential as innovators, educational environments, and co-creation facilitators, there is still a lack of evidence about their impact, effectiveness, and potential to innovate (Ballon et al., 2018; Paskaleva & Cooper, 2021; Schuurman et al., 2015). Equally, knowledge about success factors and enablers for co-creation in living labs is scarce (Greve et al., 2016). Particularly, research into the embeddedness of higher education in living labs is limited at an early stage and calls for more research on the organization and governance within this context (Tercanli & Jongbloed, 2022; van den Heuvel et al., 2021).

As off- and on-campus living labs face different challenges (van den Heuvel et al., 2021), a targeted investigation is necessary. In on-campus living labs, stakeholders primarily consist of internal university entities, which can significantly influence their roles in living labs. For example, researchers' roles may shift from participating for research purposes to a more integral, initiating, or coordinating one when living labs are situated on "home turf." Despite each campus's specific context, the overall organizational structures of universities are structured similarly. Also, less complex ownership structures, easier access to infrastructure, and a natural experimentation mindset on campus make campuses particular compared to other urban settings. Hence, campus living labs may use "their own" university premises for experimentation while applying "in-house" knowledge. The characteristic organizational structures of universities, internal stakeholders, and the specificities of the campus environment highlight the need for specific attention to on-campus living labs.

Our research responds to the calls for a specific investigation of living labs in a higher education context as we aim to uncover the challenges of on-campus living labs. Previous work on campus innovation (including living labs) concentrated on corporate decision-makers and the role of managers (Du Preez et al., 2022; Rymarzak et al., 2022), but recent work on living labs suggests including different stakeholders in future studies (Hossain et al., 2019; Tercanli & Jongbloed, 2022). Therefore, we will include the perspectives of different (intra-organizational) stakeholders, such as the corporate university staff and researchers. Set in the realm of living labs and their impact on sustainability transitions, we will focus on the challenges participants encounter in living labs working towards innovation for the energy transition.

In this explorative study, we aim to get more insights from the intra-organizational university perspective and to establish why campus living labs are not more prevalent and whether campus living labs may live up to their potential to innovate. The intra-organizational perspective allows us to pinpoint challenges arising in a specific campus context without introducing additional (external) complexities. Subsequently, conditions hindering the facilitation and innovation processes of living labs on campus might surface more clearly. Our findings contribute to the literature on living labs, especially in campus contexts, by providing comprehensive oversight and structure to encountered challenges. These challenges might enable universities to create beneficial conditions within their sphere of influence so that campus living labs are empowered to play an accelerating role in the energy transition while campuses enforce their role as innovation environments.

3.2 LITERATURE BACKGROUND: LIVING LABS AS A DRIVER FOR SUSTAINABLE INNOVATION

Experiments play a vital role in sustainability transitions (Fuenfschilling et al., 2019; Wirth et al., 2019), and different types of experiments aim to add to sustainability visions (Sengers et al., 2019). In this realm, living labs seem to be a favorable and popular context for sustainability experimentation (Torrens et al., 2019). Unlike the more typical scientific laboratories that experiment under controlled conditions, living labs operate in real-world settings (J. Evans & Karvonen, 2014) and in transdisciplinary ways, transgressing institutional boundaries and the science-society divide. This is done by integrating practice and experience-based knowledge (Alvargonzález, 2011; Klein, 2010).

However, living labs are treated as much more than real-world sustainability experiments, as many definitions, interpretations, and types of labs exist (Greve et al., 2021; McCrory et al., 2020). Several scholars have endeavored to elucidate different natures and characteristics of labs by exploring different lab concepts. In their reviews, McCrory et al. (2020) and Schäpke et al. (2018) present an overview of different sustainability-oriented lab concepts, distinguishing, for example, real-world labs, transformation labs, urban living labs, and living labs. Chronéer et al. (2019) specifically identified the key components of urban living labs while comparing them to traditional living labs. We will dive deeper into the latter two concepts in the following sections.

Different research avenues see living labs as (1) a system, an ecosystem, or a network, (2) a combined approach, (3) a context or an environment, (4) a method, methodology, or approach, (5) a tool for the enhancement and implementation of public and user involvement, (6) a development project for products, services, and systems, (7) a business activity or operational mode, and (8) an innovation management tool (Leminen & Westerlund, 2016). In general, the different notions make the concept confusing, and this inspired a number of scholars to provide descriptions of living labs' associated core characteristics, including stakeholders, user roles, participation, openness, context, coordination, aims, duration, scale, innovation outcomes, challenges, sustainability, activities, and business models and networks (Følstad, 2008; Hossain et al., 2019; Steen & van Bueren, 2017; Stuckrath & Rosales Carreón, 2021; Veeckman et al., 2013).

Westerlund and Leminen (2011, p. 20) define living labs as "co-creation ecosystems for human-centric research and innovation. (...) [T]hey are physical regions or virtual realities where stakeholders form public-private-people partnerships (4Ps) of firms, public agencies, universities, institutes, and users all collaborating for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life contexts." Two recent literature reviews synthesized that living labs are set in demarked real-world spaces (physical or virtual) that aim to solve societal challenges in transdisciplinary ways in co-creation with different stakeholders in public-private-people partnerships settings (Greve et al., 2021; Hossain et al., 2019). The European Network of Living Labs (ENoLL) presents co-creation, a multi-method approach, real-life setting, orchestration, multi-stakeholder participation, and active user involvement as the common characteristics of living labs (ENoLL, 2023).

To qualify living labs, we comply with this literature by deriving the following four characteristics from both Westerlund and Leminen's definition and ENoLL's characteristics: (1) real-world environment, (2) transdisciplinary approach, (3) co-creation, and (4) public-private-people partnership. Thus, living labs need to (1) be set in a physical setting where real-life events occur (in our case, the campus), as opposed to simulated or theoretical contexts, (2) integrate academic and non-academic knowledge and methods from multiple disciplines to address complex problems beyond the scope of any single discipline, (3) collaboratively generate value, solutions, or outcomes by (4) involving government, businesses, and users to address societal challenges or pursue shared goals.

On-campus living labs can be seen in the realm of urban living labs (König & Evans, 2013). Urban living labs use cities as learning environments for innovations and aim to increase urban sustainability across different topics, like climate change, energy transition, transportation, and food systems (Bulkeley et al., 2016; Nevens et al., 2013; Rodrigues & Franco, 2018; Steen & van Bueren, 2017; Voytenko et al., 2016). As campuses contain a city-like character in the means of facilities, various users, food outlets, infrastructure, housing, and up-and-downstream consumption and emissions, on-campus living labs compare to urban living labs. Also, in many of the described key components of urban living labs, campus living labs are similar to urban living labs. For example, campus living labs like urban living labs have a strong governance and political component as they need to be supported by decision-makers – in the case of urban living labs from cities and politicians, in the case of campus living labs, the university executive board. Further, they both have a physical representation, engage the previously mentioned stakeholders, and experiment and innovate for sustainable solutions and transformation (Chronéer et al., 2019).

A close relationship with city governments and university campuses, often being part of cities, reinforces that perception. As such, campuses can be seen as in-between spaces, vital for innovation. For instance, Schliwa and McCormick (2016) place the campus between a district and the city on a geographical scale, emphasizing its in-between character from an urban perspective. Consequently, campus living labs can be considered suitable innovation, testing, and learning fields, which can positively affect universities and wider societal and urban sustainability transitions on multiple levels (Martek et al., 2022; Purcell et al., 2019). Crucial properties of campuses for living labs focused on sustainability transitions include access and intervention possibilities into urban challenges on a smaller scale. For instance, to achieve climate neutrality, universities need to reduce their carbon emissions, particularly along their supply chain, from buildings and (re-)construction, and energy production (e.g., emissions from natural gas for heating) (Herth & Blok, 2023). These issues, which require transdisciplinary approaches, are also urban challenges addressed in living labs. On-campus, these challenges can be tackled exceptionally well due to the city-like character of campuses, reduced ownership complexities, easier access and intervention possibilities in infrastructure, and experimentation-prone users such as students.

However, universities are described as having rather inflexible structures with limited opportunities for change (Rymarzak et al., 2022). This also pertains to the implementation of living labs and innovation projects. Du Preez et al. (2022) study showed that most innovation projects (including living labs) on 13 Dutch campuses were relatively mature, comprising Technology Readiness Levels 6 and up. This indicates a lack of fundamental experimental real-world labs aligning with the above-described rigid organizational structures. Despite the growing interest in living labs, their principles, such as transdisciplinary, citizen involvement, and multi-stakeholder collaboration, seem difficult to integrate into the current structure of Higher Education Institutions (Tercanli & Jongbloed, 2022). Campus living labs might thus need to break implicit and explicit rules to create a more open and collaborative network structure (Du Preez et al., 2022; Ventura et al., 2020).

Living lab approaches inherently involve relinquishing complete control, dealing with unpredictable outcomes, and embracing failure (and the learning it brings). These issues are particularly relevant given the limited knowledge about the emergence of campus living labs. Many living labs emerge and disappear quickly (Perez et al., 2023; Ballon et al., 2018), and campus living labs typically arise ad hoc and unstructured (Martek et al., 2021). Moreover, few studies address the success and failure factors of living labs (e.g., Bergmann et al., 2021; Greve et al., 2016), and even fewer do so in campus contexts (e.g., Callaghan & Herselman, 2015), where the findings tend to remain case-dependent, making tailored facilitation of campus living labs challenging. As such, they are relatively unique within the usual university governance structures. Our study on campus living lab challenges might not only uncover roadblocks in the innovation process but also provide tentative indications of why they might fail.

3.3 METHOD

In this exploratory study, we targeted several campus living labs with the overall theme of the energy transition within the campus environment of the Delft University of Technology (TU Delft) to investigate from intra-organizational multiple stakeholder perspectives. We applied a qualitative approach and collected our data through semi-structured interviews to unravel the challenges stakeholders face in their daily operations (Creswell, 2014). A long-list of campus innovations was compiled from a list of a university corporate office and cases published by Du Preez et al. (2022). After removing duplicates, an initial set of 17 cases was selected. We evaluated if these cases comply with the previously described characteristics of living labs, namely (1) real-world environment, (2) transdisciplinary approach, (3) co-creation, and (4) public-private-people partnership, and excluded those that did not. Additionally, we consulted operation staff to ensure we did not miss any initiatives that might not be included in our long list. This resulted in a final sample of six cases (see descriptions in the following).

We conducted fifteen semi-structured interviews with campus living lab participants between March 2021 and April 2022 (see Appendix C). At least two respondents per case were interviewed – one from the university's operations side (including involved project developers and managers, mainly from the university corporate office of Campus Real Estate & Facility Management (CREFM)) and one from the research side (including a mix of professors and researchers). Additionally, we interviewed two representatives on the university's living lab vision, independent of a specific case. Here again, one university operation representative and one research representative were included.

As interviews were conducted during the COVID-19 period, they were held online via video calls; however, two took place physically on campus. The interviews lasted between 35 and 60 minutes; all were audio-recorded (with the interviewees' consent), and comprehensive interview notes were taken. Interviews adopted an exploratory approach to allow interviewees ample room for reflections, including (1) a descriptive part of the project, clarifying its goal, roles, and timeline, (2) questions about the choice for a living lab setup and its structure, (3) the added value of the living lab being on campus and for the campus, (4) the consequences of the living lab for the university, and (5) challenges and lessons learned (see Appendix D for the interview guideline).

The interviews were transcribed and verified for accuracy. Transcripts were then analyzed qualitatively by open coding using Atlas.ti 22, which aligns with the explorative character of this study (Saldaña, 2015). A second coding round was done to detect emergent patterns and create preliminary themes and categories. During both coding processes, analytic memos were written and later analyzed. The themes found in the dataset provide an in-depth view of the campus living labs' challenges described by participating operational and research staff (presented in the results section). We addressed the validity of our analysis by checking and discussing themes and their interpretations internally and reliability by sharing and back-checking themes and emerging results with some interviewees for recognition and feedback (Golafshani, 2015). Finally, we cross-checked our findings with the existing literature in the discussion section.

3.4 CASE DESCRIPTIONS

At the end of 2021, TU Delft counted 27,270 students and 6,347 employees (TU Delft, 2022a). The university campus is located in the Netherlands metropolitan region of Rotterdam and The Hague and is connected to the city of Delft. It extends over 161 ha and is one of the biggest campuses worldwide (TU Delft, 2022d). In its current strategic framework, TU Delft aims to become a climate-neutral and circular campus by 2030. Additionally, the university wants to use its innovation power for a more sustainable future and to make its campus a living lab (TU Delft, 2018, 2019). The recent sustainability vision and ambition report contains a specific subchapter on that topic. It states that “using the campus as one large laboratory is expected to speed up the experimentation, evaluation, and implementation of new solutions that contribute to the sustainable development goals” (van den Dobbelsteen & van Gameren, 2021, p. 52). The Executive Board decided in November 2022 to invest 100 million euros in executing the sustainability plan to increase the campus sustainability. A significant part of the budget (20 million euros) is reserved for facilitating future innovations and living labs (to be developed) (TU Delft, 2022c).

The following table briefly presents the cases included in the study sample, indicating the development phases of preparation, running, or completion at the time of the interviews.

Table 3-1: Description of study cases on the TU Delft campus (alphabetical order)

Case	Description
Brains4Buildings	Brains4Buildings aims to reduce energy consumption, flexibly respond to energy supply, demand, and user behavior, and increase user comfort in buildings by developing methods using big data derived from the Internet of Things devices, smart meters, and management systems. The project includes 39 partners and plans for 7 living labs. One of them is located at TU Delft; it is themed around smart buildings, installing sensors and AI in buildings. Development phase: The project is running with the living lab at TU Delft in preparation.
Development of new campus area	TU Delft is developing a new campus area in the southern part of the campus. New buildings and location development are planned, and the first building projects have started. Sustainable innovations and living labs will be profoundly integrated from the beginning, especially in the energy system. The first building projects are already in the construction phase; the full development of the area will take much longer (in the coming decades). However, the preparation and development phase must already include infrastructure and room for living labs and innovations. Development phase: In preparatio
E-bike charging station	The solar e-bike charging station was built on campus in collaboration with students from two faculties, researchers, and the Campus and Real Estate corporate office. It contains PV cells that deliver direct current to charge e-bikes parked directly at the innovatively designed structure. Student projects and monitoring are continuously running. Development phase: Artifact completed and in operation
Geothermal well	The drilling of a geothermal well on campus started in December 2022. The geothermal well will provide sustainable heat to the campus and neighboring city districts. The share- and stakeholder setup includes TU Delft, researchers, and energy companies, all striving to develop an innovative business case for the project. The well will provide heat and a worldwide hotspot as a real-life and running research location on geothermal energy and the energy transition, the heat network, and the business case development. Development phase: Running

Table 3-1: Continued

Case	Description
Innovative façade	A small number of innovative façade panels were tested on one faculty building and then scaled up to a whole façade on another. The indoor climate behind the façade is measured and monitored. Also, a circular business model was worked out but ultimately didn't come into practice. The stakeholders included, e.g., TU Delft's Campus and Real Estate corporate office, researchers, banks, and companies. The façade is installed, and data monitoring by researchers is running. Development phase: Artifact completed and in operation
Parking garage Rotterdamseweg	The parking garage is newly built on campus. It includes roof PV panels and a wooden façade with plants and bird nests to combine electricity generation and biodiversity. PV panels will be installed on the façade, for which TU Delft researchers calculated the yields and the best positioning. Additionally, smart e-charging stations will be installed, together with battery storage and a local mini-grid. Development phase: In preparation

3.5 RESULTS

We structured our results as follows. First, we present the perceived opportunities of on-campus living labs under study (5.1). Next, we provide an overview of challenges faced by campus living labs, categorized as internal (5.2) and external (5.3), both pertaining to a living lab's point of view. Figure 3-1 illustrates the interrelation of challenges with internal challenges situated within the initiatives of campus living labs, while external challenges pertain to the broader campus and organizational context within universities. It is worth noting that campus living labs and the campus itself are embedded within a wider context, as depicted in the figure and established previously.

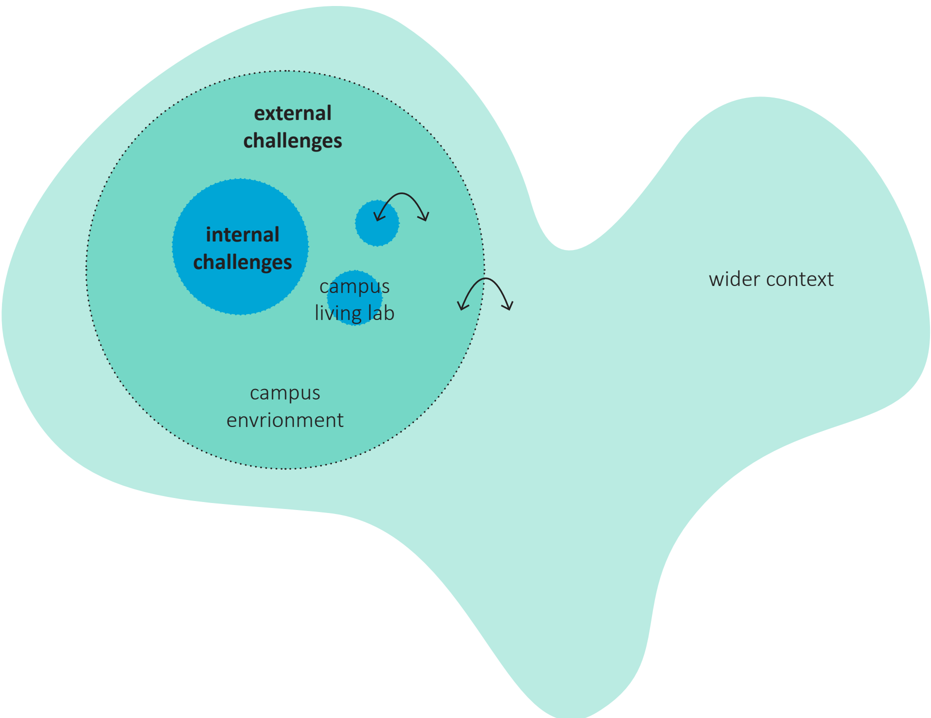

Figure 3-1: Interrelation of internal and external challenges within the wider context

At this stage, the ideal-type living labs described in the literature do not appear to be fully realized on the campus, as our cases deviate from this ideal by not fully aligning with all dimensions. Previous studies confirm that many living labs deviate from that ideal type in practice (Greve et al., 2021; Steen & van Bueren, 2017). Nevertheless, we argue that our cases qualify as campus living labs as all these initiatives are aimed at co-creation and innovation in a real-world setting (see Appendix B), targeting societal challenges from the outset. In particular, the user integration dimension seems to be the bottleneck to ideal-type living labs for the investigated cases. We will discuss this dimension in more detail in the remainder of this article.

3.5.1 Opportunities for living labs and benefits for the campus

The university campus was considered favorable in all cases under study - a space where theory meets practice. Opportunities for the living labs to be on campus and for the campus to host living labs were mentioned, like bridging industry and academia, an experimentation mindset, and many networks and stakeholders being present naturally.

The closeness to academia, state-of-the-art knowledge, and prestige of working with a renowned university were seen as attractive for third-party stakeholders to engage on campus. As was the university's lack of commercial interest, which leaves room for innovations.

Campus living labs promise practical experiences for researchers and students, as well as immediate relevance of the research and outcomes by tackling societal questions. Researchers valued the possibility of using the premises "in front of their door" instead of searching for other suitable places and getting access to buildings, infrastructure systems, and data that would otherwise be inaccessible:

> *"It provides access that you normally don't have (…) And it offers tremendous value for researchers because they can get other kinds of data that are usually free of proprietary or other legal constraints [on campus]." 1:5*

Further, campus living labs were believed to draw extra funding, which is becoming increasingly important for the university's finances. They were also mentioned to contribute to the campus sustainability goals, showcasing what the university is working on, what can be done on a bigger scale, and which challenges might be encountered, which might increase the organization's credibility regarding its sustainability ambitions and accelerate the university's sustainability transition.

> *"(…) the advantage could be that if things work out, they can get extra funding, perhaps to improve the buildings, and in various ways, they might achieve these carbon footprint objectives more easily or in a better way, with the help of researchers." 1:27*

Various interviewees stated that campus living labs have the potential to improve campus quality and attract and bind external partners, top researchers, and students, which might translate into a competitive advantage.

Sparking enthusiasm through visibility and radiance, communication, and public relations opportunities were other benefits mentioned, along with educating the public. The latter includes getting the public in contact with innovations, fostering acceptance, translating research to practice, and showcasing the university's research activities with tangible results. Also, according to a participant, campus living labs distribute costs and can be seen as an investment with a return on research and infrastructure. Likewise, a strong motivation of most respondents was to use existing assets and "practice what you preach." Nevertheless, the living lab concept was also used in a typical buzzword sense, as one respondent explained: *"We use the word living lab because it's deep, and it gets funding." 24:6*

3.5.2 Living labs face internal and external challenges on campus

3.5.2.1 Internal Challenges of living labs on campus

Internal challenges are those perceived as internal from a living lab's point of view and are categorized as organizational, collaboration, and acceptance challenges.

Organizational challenges

Organizational challenges include the coordination of the different stakeholders, roles, motivations, goals, decision-making processes, a common definition or understanding of living labs, questions of ownership and responsibility, funding and financing, monitoring, scaling, impact, and continuity. The interviews showed a lack of understanding of what living labs are about. *"Not everyone understands the iterative nature of a living lab setup. It's confusing and repetitive at the same time." 24:21* Even respondents within the same initiative had different understandings:

> *"There was a lot of confusion, I must say, different types of understanding of what we're doing until today. Which was a big challenge." 16:12*

To overcome that issue, the respondents explicitly mentioned that they would spend more time and effort in the initiation phase to clarify each stakeholder's motivations and goals.

> *"I think we really had the idea that we understood everyone's motivations, and it was very clear that we didn't. And there were things people really cared about that we did not understand from all different sides. And those motivations, I think, should have much more attention. (...) I think just having those preconceptions, those concerns, those motivations, very clearly detailed, and not superficially, really spend time on digging into what these mean as well, would be really helpful." 14:51*

None of the cases strategically monitored the overall (innovation) process. Since engaged individuals initiated the living labs, monitoring was not a primary concern, yet a tracking and monitoring system would later seem beneficial.

> *"(...) Well, at the beginning of the process, we didn't know how big of a process it was, which I think was part of the issue; we thought it could be relatively simple. (...) So we didn't start the process with such an idea that it would take quite a long time and that we should really monitor the process in detail." 14:45*

Besides, no visions or wider goals were defined other than those directly related to the project's realization. Nevertheless, all cases were believed to have a direct scaling potential on or outside the university campus. On campus particularly, even the continuity of living labs, like the further development or stacking of projects beyond the current concrete project realization, does not seem to be the norm.

Funding and financing are seen as central challenges. Campus living labs were assumed to require more resources (time, people, and money) than traditional projects and have to deal with complex stakeholder settings. Since they operate in the real-world environment, they often require a viable business case to get off-ground. However, for a viable business case, one party's commitment is often needed to carry the "initiation risk." Without anybody taking that risk, there is no viable business case; without a viable business case, nobody wants to take the risk: the well-known chicken-and-egg problem.

Collaboration challenges

Collaboration challenges include learning and knowledge sharing, complex decision-making, resources, flexibility and alignment, and new working methods. Respondents reported no cross-campus living lab knowledge flow about, e.g., common organizational challenges, which leads to repeatedly finding individual solutions.

Decision-making requires *“consent of all parties, and you need to be very open about what you’re doing” 16:13*, making collaboration and co-creation with multiple stakeholders complex. It also involves addressing decisions about resource allocation and contributions in untraditional or previously unknown ways, and questions of ownership and responsibility. These new ways further concern the need to align various stakeholders’ distinct cultures, rhythms, motivations, goals, and plans while being open and flexible. This required time investment and was perceived as a slow process with *“literally hundreds of meetings.” 16:23*

Besides, we observed a lack of user integration in our cases. We categorize this as another internal challenge, as the integration of users is central to the concept of living labs.

Acceptance challenges

Challenges related to acceptance concern past experiences and new ways of working, trust, and making room for mistakes and uncertainty. According to the respondents, campus living labs ask stakeholders to open systems and infrastructure. Several researchers mentioned the challenge of overcoming past experiences regarding attempts to initiate campus projects that resulted in having bad experiences and negative emotions, like frustration and indifference. This hinders trying again – even though circumstances might have changed. It also shows a mutual need to respect each other’s roles in the university environment.

> *”If you come up with a good idea and you don’t respect the needs of Campus Real Estate [CRE] - their most important job is to facilitate the operation of the campus in the smoothest way that we can think of. If you don’t respect that and just say, hey, I have a great idea, let’s go for it. Yeah... On the other hand, CRE needs to be aware that they are on the smartest campus that we can think of. So let’s bring in our expertise to stimulate campus as a living lab.” 23:52*

3.5.2.2 External Challenges for living labs on campus

External challenges, from the perspective of the living lab, are categorized into university organization, resources, coordination, campus, and bridging operation and academia.

University organization

The university organization is a traditionally hierarchical and rigid structure. Since different university entities have different roles, goals, and aims, the decision-making process was perceived as complex and layered. No campus living lab frameworks or processes were in place, so decision entities lacked guidelines and mandates. Clear instructions from the university's top-level leadership are required to provide a mandate and flexibility in project management processes to integrate living labs:

> *"So if the facilities managers [project managers for campus development] are told that the university expects them to involve the academic community, then they have a clear instruction and a mandate to follow, which otherwise could also be done without the involvement of the research community." 1:29*

Campus living labs did not fit the existing organizational structures as they did not align with the university's standard project management practices and processes. They differ from traditional projects and require new decision-making, integration, and collaboration processes. This also concerns legal questions, flexible processes, and room for mistakes. Without guidance in these new ways of thinking and working, it would be *"maybe easier not to do it" 2:26*. Especially since the current structures, (selection) criteria (e.g., in tenders), roles, and processes do not allow for experimentation, flexibility, and uncertainty. As campus living labs are not defined tasks for operations, there is also little room in project planning for them.

> *"Because if [the planning] remains tightly within its assignment, then there is actually little room for a living lab there" 20:44*

As long as they are not embedded in processes and evaluation criteria, the potential to strategically use campus living labs as innovation tools is not realized.

Resources

Questions of resource allocation and funding are internal as well as external challenges. Externally, it concerns the resource allocation and funding in the university organization. This is tightly linked to the support and assigned importance (and thus granted resources) of the university's top-level management. Resources include space, human resources, financial resources, dedicated processes, and coordinators. A scientist mentioned:

> *"I think it causes quite some time to be invested both from CRE, from the researchers, etc. So we could do some of this research by working with others on other projects, and we would spend much less time on the organization. So we have to decide where to invest. And I think that the university as a whole is not yet aware maybe of what those costs are, because it's sort of hidden in additional work" 14:69*

If campus living labs are not embedded organizationally, they are considered voluntary extra tasks or side projects, depending on individuals and ad-hoc emergence. *"Now it is ad hoc based on individuals who may or may not want it." 20:81* Even though interviewees unanimously called for a campus innovation/living lab coordinator or manager, they repelled another centralized entity.

> *"I don't think it should be centralized. But there is a support system that's missing in terms of knowledge sharing, and then monitoring and evaluation and an overview of projects. (…) And I don't believe the answer is centralizing. (…) I think it would be restrictive. You would put a bottleneck in something that's already really quite lively." 24:92, 99, 103*

Coordination

All respondents noted that their projects were not strategically coordinated but bottom-up initiated and depended on individuals' enthusiasm, willpower, negotiation skills, capacity, and stamina.

According to the interviewees, campus-wide coordination could support financing possibilities, link stakeholders, connect people, provide transparent decision-making structures, support internal and external communication, facilitate project processes, and create a platform for knowledge sharing and cross-fertilization.

> *"I think you would need a website with guidance on how to set up a living lab; what are the ingredients? What are the pros and cons? Why would you do this? And then take you through a step-by-step on how to get a living lab set up. What do you do, what can you expect for an outcome, and then how to run that on campus? But that should be managed by a living lab office or coordinator or someone who understands academics, project management, commercialization of projects, innovation, ecosystems, startups, getting funding. (…) According to me, someone needs to be assigned the job of setting that up." 24:53, 54*

An internal shared understanding of what campus living labs are was considered essential to provide a baseline and to better align and coordinate scientists and operations. Interviewees also mentioned challenges regarding monitoring and the continuity of campus innovation projects (stacking projects, where one leads to the next). Knowledge-sharing networks were not in place to establish collaborations, facilitate continuity, foster cross-case learning, and exchange organizational practices. Knowledge was considered to flow outside rather than be implemented within the university.

> *"How is it possible that we don't see what we are working on and spin-offs from TU Delft that have brilliant ideas? They sell their expertise to places all over the Netherlands, but there's nothing of their expertise to be found on campus. That's strange." 23:61*

Campus

Being the campus owner, the corporate office CRE has a high decision power regarding campus living labs. For example, the allocated location for one of the cases was rather un-functional. Permission for the campus living labs and their potential location is needed, which depends on CRE and the aesthetics committee, and the alignment with CRE's campus strategy. The university is believed to introduce more risks to its operation by allowing innovative initiatives on campus, while the campus' reliable operation must be ensured. Integrating living labs was seen as difficult due to the rigid, complex environment and a relatively closed community with its own rules and culture. This might work as an obstacle, as a respondent puts it:

> *"A campus also has its own rules. Its own culture, its own elasticity or a lack thereof, its own priorities. So that can also be a hindrance." 18:37*

Bridging university-internal worlds – operations and science

We came across various challenges related to the university's different internal roles and ways of working - operations and academics, both of which are inherently involved in campus living labs.

University operations and academics are perceived from both sides as highly separate and are repeatedly called *"two parallel worlds" 20:39*. This translates into different perceptions of what campus living labs are and mutual expectations about roles and responsibilities. Operation staff handles living labs as standard projects they facilitate, whereas researchers see them as knowledge implementation, -creation, and research places. Scientists are highly motivated to apply their knowledge and expertise in their backyard; however, they do not want to manage or take ownership of the campus living labs.

These dynamics are further complicated by, e.g., operation entities sometimes fulfilling different roles. CRE acts as a stage gate for innovations to be facilitated on campus (external for campus living labs). Simultaneously, CRE can be a campus living lab stakeholder, e.g., in the user role (internal for campus living labs), or both. The different layers lead to unclear roles and responsibilities on strategic, tactical, and operational levels.

The interview results showed that as long as campus living labs are not formally embedded in operation processes and evaluation schemes (e.g., integration in selection criteria, tenders, key performance indicators, and reward systems), their execution is an extra task and an additional risk for operations. Living labs are contrary to what operation staff is expected to do, namely securing the functioning of the campus with minimal risk and delivering high-quality projects on time and within budget. Their focus is thus realizing a specific project assignment, as expressed by an operation staff respondent:

> *"I just got that assignment to make sure those parking spaces are there. (…) Yes, and when [mentions name] came to me like, we also have to do this [integrate a living lab], I thought to myself that it would just cost an extra year. I wasn't very happy with it at first. (…) Our real estate development very much needed to continue, and [I had] to make sure that the living lab story wouldn't affect the planning of my project." 19: 30, 37, 41*

Alignment issues of operation and scientists is another issue. It concerns the often-diverging project and research planning and campus development timelines. Operation's campus projects often have strict lead times with little leeway for experimentation, higher risks, uncertainty, and unexpected outcomes. In contrast, research planning needs to allow time for, e.g., hiring new researchers when funding is granted and the mentioned unexpected outcomes. Whereas academic break times are excessively used for operation projects, academics often only then have the chance to take a break from education and teaching, which complicates alignment.

3.6 DISCUSSION

3.6.1 Moving campus living labs forward – Discussion of the results

Although we found many of the expected opportunities of being on campus, fewer living labs were initiated on our campus than expected. This emphasizes the importance of getting insights into the challenges for campus living labs in the distinct university environment. Campus living lab participants mentioned indeed numerous challenges they encountered in their daily operations. First, a number of participants experienced the complexity of their projects as hindering the innovation capabilities of their labs. Second, living lab participants acknowledge the tensions between the traditional university structure and the open-ended nature of their labs. This leads to a perception of operating in two parallel worlds (operation and science), which challenges the potential to innovate as it seems hard to integrate these two ways of thinking and hinders collaboration. Third, campus living labs struggle with their internal organization structure as there are no clear guidelines on organizing their lab, and many encounter the incremental search for a suitable structure as hindering their progress.

The university campus holds invaluable assets for innovations, providing safe experimenting conditions in a real-world environment and hosting great intellect. Yet, in our case, campus living labs are not used as strategic tools for innovations and the university's sustainability transition (nor were our cases included in education and curricula, for that matter). This aligns with Lough's (2022) statement that HEIs are not living up to their potential in creating social value by advocating for and scaling their innovations. Our results show that top-down and bottom-up initiatives are needed to tap into that potential.

Currently, it seems that the campus living labs are facilitated by university staff who treat living labs as standard (demonstration) projects with Technology Readiness Levels 7–9. As such, decisions are made on an ad-hoc basis without any proper understanding of the specific nature of living labs compared to standard projects (Du Preez et al., 2022). Thus, campus living labs are handled based on a traditional project logic, and this "projectification" of experimentation where a project logic forms the base (Torrens & Wirth, 2021) is not a favorable breeding ground for living labs. Their approach is more explorative and open to unintended outcomes and innovations, including more room to maneuver and failure. This makes the intent with which living labs are set up inherently different than projects.

Also, research shows that living labs need long-term funding to keep them alive and to sustain the innovation activities and their scale-up. However, they are usually financed on a project basis, which does not fit with the number of unforeseen outcomes such labs encounter (Hossain et al., 2019). Thus, transparent decision-making criteria must be created to avoid these unmotivated ad-hoc decisions and prevent financing only experiments that fit into the established project logic. The buzzword issue of labeling projects "living labs" for funding or publicity shifts the focus from solving core challenges to simply being or becoming a living lab. This is facilitated by a lack of common understanding of what a campus living lab constitutes, which is problematic internally and externally, as implications might diverge substantially (Save et al., 2021).

For instance, we noticed that our cases differed in scope, as some represent single living lab initiatives, while others are rather umbrellas for various living lab initiatives. The latter is the case for the Brains4Buildings and the development of a new campus area. These two layers correspond to what Schuurman (2015) calls the living lab organization and living lab project. These different perspectives emphasize the need to create clarity and a common understanding within the university. Additionally, if other potential issues are unclear to stakeholders, e.g., uncertainty, unpredicted outcomes, failure, and learning during the process, this could cause problems due to different expectations. Thus, intensified communication and specific motivation, expectation, and goal management for all stakeholders are necessary (Leal Filho et al., 2022).

Considering the traditional organizational setup of universities, front-end user integration is not a traditional practice. Our findings revealed that user integration had the weakest compliance among the four identified characteristics (refer to Appendix B). Similarly, Steen and van Bueren (2017) found that user integration for co-creation was lacking in many urban living labs as well. Yet, not integrating users from the front end can be understood as a missed opportunity and belittling their role in the innovation process. As such, this somewhat violates the user-centeredness of living labs, but this seems not uncommon in university contexts where the role of users is often not yet clear. This is in contrast to urban living labs, where citizens play a clear and vital role as users. On campus, the users are often part of the multi-actor university's operation and administration and are much less clearly identified. In this respect, the potential multi-actor role of the university makes it vital to clarify the different roles within a campus living lab.

The organizational and process hurdles hinder innovations as living lab members report spending energy sorting out administrative issues continuously, also addressed by Callaghan and Herselman (2015). As suggested by Martek et al. (2022), setting up a university-wide support network for living labs may indeed help to facilitate their administration and coordination activities. The question remains where this facilitation point should be located in the organization and what responsibilities should be mandated (Tercanli & Jongbloed, 2022). Some of our respondents opposed yet another centralized university body and argued that the facilitation process needs co-creation, flexibility, and experimentation itself to deviate from the traditional project approach, which does not fit with the innovative nature of living labs. Also, innovation coordination and integration should become part of the overall university operations. Consequently, this requires changes in existing structures, e.g., project timelines and requirements, to allow for flexibility and co-creation (J. Evans et al., 2015). As the impact of the existing campus innovations still seems incremental, better organizational facilitation and integration could free up capacities to innovate and may lead to an increased impact of living labs.

The identified challenges call for transparent organizational structures, decision-making, and integration of campus living labs into current operational processes and reward structures (Save et al., 2021). To that end, an internal reframing of living labs is needed. Instead of seeing such labs as a risk factor, they need to be understood as opportunities to contribute to the (campus and societal) sustainability transition, which also includes the integration of society in the role of users. This aligns with universities' (third) mission and may contribute to overcoming disciplinary and operational silos in and around the university environment. Under these conditions, campus living labs could then function as intra- and extra-organizational boundary spanners to drive innovations (van Geenhuizen, 2016). Consequently, traditional roles in the university organization and the science-society divide must change to enable co-creation, co-ownership, and more flexibility in standard processes to simplify alignment and prevent possible lock-ins (Rymarzak et al., 2022).

Although we studied the challenges of living labs from the perspective of one university campus, our findings may apply to living labs at other university campuses as these contexts of the university organizational settings are comparable. Despite some local specificities, we believe campus living labs may encounter the challenges we have detailed through our study. The awareness of these potential challenges might pave the way for adequate preparation and better operations of campus living labs and may avoid getting stranded before reaching their goals.

3.6.2 Limitations and future research

Limitations of this study include the single focus on one university campus, which limits its generalizability. Nevertheless, as mentioned previously, we assume our findings are applicable to other comparable university campus settings. In line, we encourage comparing campus settings and their implications for on-campus living labs. Next, our work presents results derived from data gathered in a relatively short period, representing the current situation at that point in time. However, living labs are dynamic and organic in their development. This is why longitudinal studies would be valuable for tracking their progress over time. Finally, we focused this work on the intra-organizational university stakeholder perspective, omitting third parties and potential users and students. The diversity of cases and their different phasing make it difficult to include all stakeholders. Again, longitudinal studies could also create more room to integrate their views. The same applies to the different types and organizational layers of living labs. Including them could help specify the challenges further.

Although our scope was narrow, our findings may still apply to other settings. However, making general statements would exceed the scope of this study, which is why we highlight several avenues for future research. Including other Higher Education Institutions to compare different types of campuses (e.g., city and rural) and their location-specific challenges would be valuable in understanding if and how other environments are better equipped to facilitate living labs. Similarly, comparing organizational facilitation and embeddedness could help create optimal environments for living labs. Additionally, we are calling for studies that investigate how far our findings might apply to other contexts beyond the campus. It would also be valuable to assess whether users and third parties recognize our findings and to identify any additional challenges in that process.

We see the need for more empirical research on the success factors of campus living labs, as simply overcoming the challenges mentioned here might not automatically ensure their success. Since we saw campus living labs facing the same challenges and continuously reinventing the "living lab wheel," we encourage future research to develop phase-related oversights of tools and structures to support living labs' coordination, governance, and learning processes. Furthermore, new approaches would be desirable to ease the way from a campus with fragmented, ad-hoc, single-case living labs to an integrated "Campus as a living lab" perspective. As these processes themselves will need and entail co-creation, unexpected outcomes, failure, and learning, tracking and sharing them would be of value. For innovation and living labs, an open culture of mistakes is vital. However, very few failed living lab cases are published in the literature, which does not align with that proclaimed culture. It also means losing shared, valuable learning opportunities for living labs, their hosting organizations, and stakeholders.

3.7 CONCLUSION

Although university campuses seem ideal locations for co-creation and innovation through living labs, many universities fail to use these arrangements to their full potential. This is especially pertinent for various experiments related to sustainable future initiatives. Our study shows several internal and external challenges which hinder living labs in their progress towards the energy transition on campus. Such internal challenges include the need for a clear living lab setup and front-end user integration, well-coordinated administration, and effective governance to facilitate stakeholder collaboration. External challenges relate to the difficulty of embedding living labs into the traditional organizational structure of the university, as well as tensions between academic and operational processes. Despite these challenges, university campuses remain fruitful locations for living labs to co-create and innovate as long as future initiatives are fittingly facilitated by the university administration and the internal organization of living labs is further developed. This will enable living labs to unlock their potential and contribute to complex societal challenges, such as the acceleration of the energy transition sooner rather than later.

In Chapter 3, we uncovered several challenges living labs face on campus but also concluded that campuses remain favorable environments for living labs to thrive. Even though awareness of these opportunities and challenges might lead to better-targeted design and facilitation, it does not automatically translate into successfully enabling on-campus living labs. Therefore, this chapter investigates the enabling factors needed to bridge that gap and to create the conditions to facilitate them successfully. We conduct a systematic literature review of on-campus living labs, providing an extensive overview of essential factors. Recognizing that different development phases of living labs translate into different needs, we also map these enabling factors across the various phases with input from an expert panel. This mapping offers insights into the relevance of each factor throughout the development process. Our findings contribute to the literature by presenting a comprehensive list of enabling factors and highlighting the importance of considering living labs' development phases. Practically, our results assist Higher Education Institutions and living lab practitioners in successfully facilitating on-campus living labs during any development phase, fostering a more supportive environment for innovation.

Chapter 4

How can on-campus living labs flourish?

A previous version of this chapter was accepted for publication as:
Herth, A., Verburg, R., & Blok, K. (in press) How can campus living labs thrive to reach sustainable solutions? *Cleaner Production Letters*.

Spelling and formatting have been aligned throughout the dissertation.

ABSTRACT

Many Higher Education Institutions utilize living labs to address complex societal challenges and foster innovative solutions on campus. Despite the perceived benefits of campus environments for transdisciplinary real-world innovation, living labs often encounter challenges. As such, there is a growing need for more knowledge on facilitating these on-campus initiatives in different development phases. Here, we investigate enabling factors for on-campus living labs and establish their salience across the living labs' development process. First, we conduct a systematic literature review, identifying sixteen enabling factors. The most pertinent ones are stakeholders and networks, coordination on the organizational level, a conducive work culture, co-creation and collaboration, and suitable methods and practices for living labs. Second, we assess all factors' relevance across living labs' development phases through the input of an expert panel. To that end, we developed a mapping exercise, which can in itself serve as a discussion tool for living lab practitioners. Our results suggest that the initiation phase relies on leadership, coordination, stakeholder engagement, a conducive work culture, and funding. In contrast, operational phases are enabled by shared understanding, internal management, stakeholder collaboration, methodological appropriateness, and evaluation. Lastly, the dissemination phase hinges on transfer, scaling, evaluation, learning, and bridging stakeholders and contexts. These insights contribute to a better understanding of enabling factors for campus living labs during different phases of development, offering tailored guidance for stakeholders while stressing adaptability to local contexts. Subsequently, campus living labs may be better equipped to effectively generate sustainable solutions for our time's complex societal questions.

4.1 INTRODUCTION

As hubs for knowledge creation, dissemination, and transfer, Higher Education Institutions (HEIs) are vital for sustainable development (Cortese, 2003; Findler, Schönherr, Lozano, Reider, & Martinuzzi, 2019; Trencher, Yarime, et al., 2014). They contribute to society through education and research and serve as role models by showcasing sustainable transitions through on-campus living labs (Rivera & Savage, 2020). Here, complex societal challenges related to sustainable solutions are tackled by diverse stakeholders within real-world settings and by explicitly involving users (Hossain et al., 2019). As such, on-campus living labs not only impact campus sustainability but may also contribute beyond the organizational borders through HEIs' third mission (Rivera & Savage, 2020). The rising popularity of living labs has resulted in numerous definitions and interpretations across disciplines (Greve et al., 2021; Leminen & Westerlund, 2019; McCrory et al., 2020).

Research suggests that on-campus living labs can enhance societal research relevance, yield economic benefits, attract public attention, and secure funding (Herth, 2024b; Vargas et al., 2019). Further, HEIs can mobilize diverse stakeholders and create "neutral" innovation spaces, such as living labs. Such spaces are ideally free from organizational pressure and have the opportunity to connect research, teaching, and societal relevance (Molinari et al., 2023; Purcell et al., 2019; Tercanli & Jongbloed, 2022) and may bridge the theory-practice gap between the academia and society (Bauwens et al., 2023; Compagnucci et al., 2021).

Specific to their context and location (Nyborg et al., 2024; van den Heuvel et al., 2021), on-campus living labs encounter several challenges in their internal operation and external environment, such as their cultural embedding, heterogeneous HEI-internal stakeholder expectations, and navigating their complex inner dynamics (Herth, 2024b). Some scholars highlight the inherent ambiguity of their inner workings and the emergence process of campus living labs', which challenges the understanding of their processes and practices for replication (Callaghan & Herselman, 2015; Save et al., 2021) and often leads to perceptions of living labs being obscure, ad hoc and eclectic (Herth, 2024b; Martek et al., 2022). This hints at various challenges in different living labs development phases, i.e., preparation, start, value creation, and scaling/transfer. Therefore, it is necessary to intentionally facilitate living labs tailored to their contextual and phase-specific needs, calling for investigating phase-specific enabling factors. HEIs can unlock the potential of their sustainable campus landscapes through more research on its critical requirements (Gomez & Derr, 2021).

To date, preconditions and enabling factors of living labs across contexts remain ambiguous and case-dependent. Despite calls to move beyond single case studies for more generalizable insights (e.g., Köhler et al., 2019; Sengers et al., 2019), much of the existing literature focuses predominantly on case studies (Bergmann et al., 2021; Martek et al., 2022). Therefore, some call for more systematic investigations (Berberi et al., 2023). Therefore, this study aims to identify and analyze enabling factors for on-campus living labs. Since living labs' different development stages translate into varying facilitation needs, we also aim to highlight the salience of enabling factors across these phases. By presenting a comprehensive overview, prioritizing these factors, and considering their relevance at each stage, we enhance the understanding of what facilitates campus living labs. Practically, our results aid HEIs and living lab practitioners in enabling on-campus living labs more successfully at any development phase.

Enabling factors are defined as the conditions, practices, and processes necessary to facilitate the well-functioning on-campus living labs to achieve their sustainable innovation aims. In response to calls for more research on enabling factors across campuses (Bergmann et al., 2021; Leal Filho et al., 2022), we employed a two-step approach. First, we conducted a systematic literature review to identify and categorize enabling factors and determine the most discussed ones. Second, we mapped out the most salient factors for each development phase with input from an expert panel.

Our findings provide a deeper understanding of the enabling factors at the different development phases of campus living labs. With this, campus living labs may be better equipped to tackle the complex societal questions of our time effectively.

4.2 METHODS

We followed a two-step approach to serve the research aim. First, we conducted a systematic literature review to derive enabling factors from the academic literature and thematically analyzed them. Second, we consulted an expert panel to validate the enabling factors found in step one. Further, we mapped them on the living lab development phases with the help of those experts to contextualize and specify their salience. An overview of the methodological process of this study is summarized in Figure 4-2.

4.2.1 Systematic literature review to derive enabling factors

We systematically reviewed the campus living lab literature following the PRISMA guidelines and checklists (Page et al., 2021; Rethlefsen et al., 2021). We conducted our searches in March 2023 on the Scopus and Web of Science databases, as they reflect the academic publication realm. We excluded Google Scholar due to its significant non-journal publication share (Martín-Martín et al., 2018). The search was limited to English-language journal articles to ensure alignment with the current scientific discourse. No limitations on the time frame of publications were applied. Our search terms, such as "living lab*, campus lab*," "university," "higher education," "success factor," "lesson learned," and related variations, were required to appear in the title, keywords, or abstract. The complete search string using Boolean operators is provided in Appendix E. An independent colleague discussed and peer-reviewed the search strategy.

The search yielded 482 records from the two databases (see Figure 4-1); twenty-one were included in our sample for full-text analysis. The rest were excluded in two stages due to off-campus location or divergence from our living lab definition (as described in the Introduction). Those articles were published relatively recently, from 2015 to 2022, with a peak of seven in 2021. Predominantly, they report a Western perspective with cases in Europe, Australia, and North America. Other cases were in Turkey, South Africa, Malaysia, Mexico, and Chile. An overview of the articles included in our sample can be found in Appendix F.

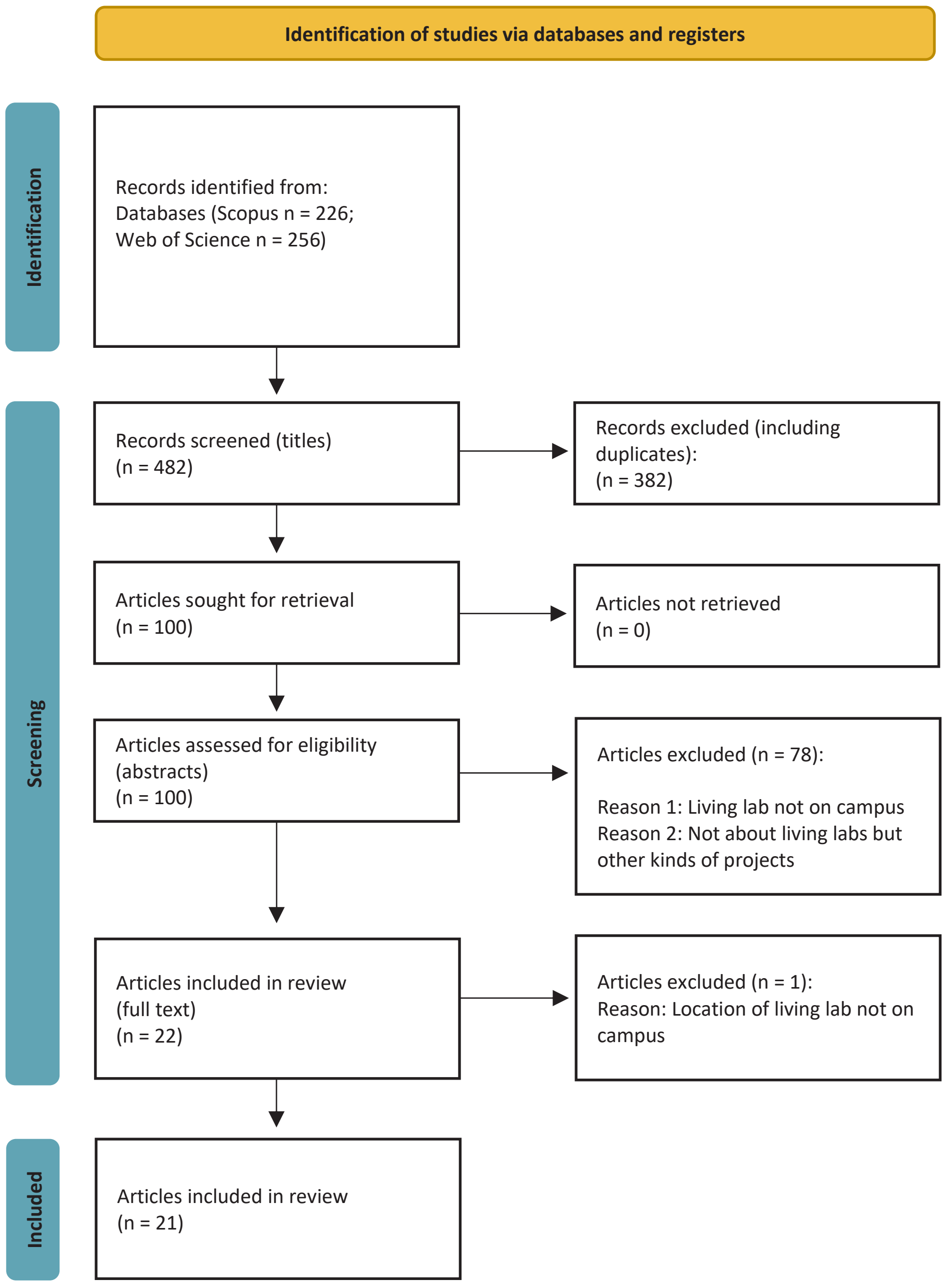

Figure 4-1: PRISMA flow diagram of the literature search and selection process, according to Page et al. (2021)

Aligning with the explorative nature of this study, we conducted a thorough thematic analysis by open coding enabling factors in Atlas.ti 23 (Saldaña, 2015), including analytic memo writing. A second coding round was conducted to identify thematic clusters and establish categories. While socio-technical systems categories inspired our category building (Fuenfschilling & Truffer, 2014; Neyer et al., 2009), we allowed categories to emerge organically from the data. These categories are not mutually exclusive, allowing codes to appear in multiple categories, reflecting their complexity and interdependence. We continuously discussed the process and codes within our research team and sought external validation by discussing random samples with researchers outside the organization (Golafshani, 2015). Last, we conducted a document analysis of the categories to establish the most discussed ones, hinting at their relevance (Bowen, 2009).

4.2.2 Expert panel session to validate and structure the enabling factor categories

In the next step, we aimed to validate the 17 preliminary categories and determine their relevance across the development phases of living labs. Given that the literature did not provide clear insights into the phases when discussing the enabling factors, we consulted field experts for this step. This involved a three-step iterative process. First, we sought validation of the categories from three experts. Their feedback resulted in merging categories to a final set of 16.

Second, an international expert panel of eight participants with direct research or practice experience in campus living labs was engaged and selected from the author team's network. The group consisted of researchers, living lab managers, and coordinators who have contributed to conferences or published articles in the field. They were affiliated with six universities or research institutes in the Netherlands, Sweden, and Canada. We sent those experts a presentation outlining the different living lab development phases in short video statements, together with the content and meaning of the categories in info boxes, asking them to map the categories to the most pertinent phases. Participants could assign categories to multiple phases or indicate their relevance across all phases. They were also encouraged to comment on content and the mapping process. A blank mapping slide and an exemplary result can be found in Appendix G. Seven of the eight participants returned their results. We calculated interrater reliability for each phase using Fleiss Kappa to assess agreement among participants beyond chance. Fleiss Kappa determines the level of agreement among raters beyond what would be expected by chance alone (Gisev et al., 2013; Nichols et al., 2010).

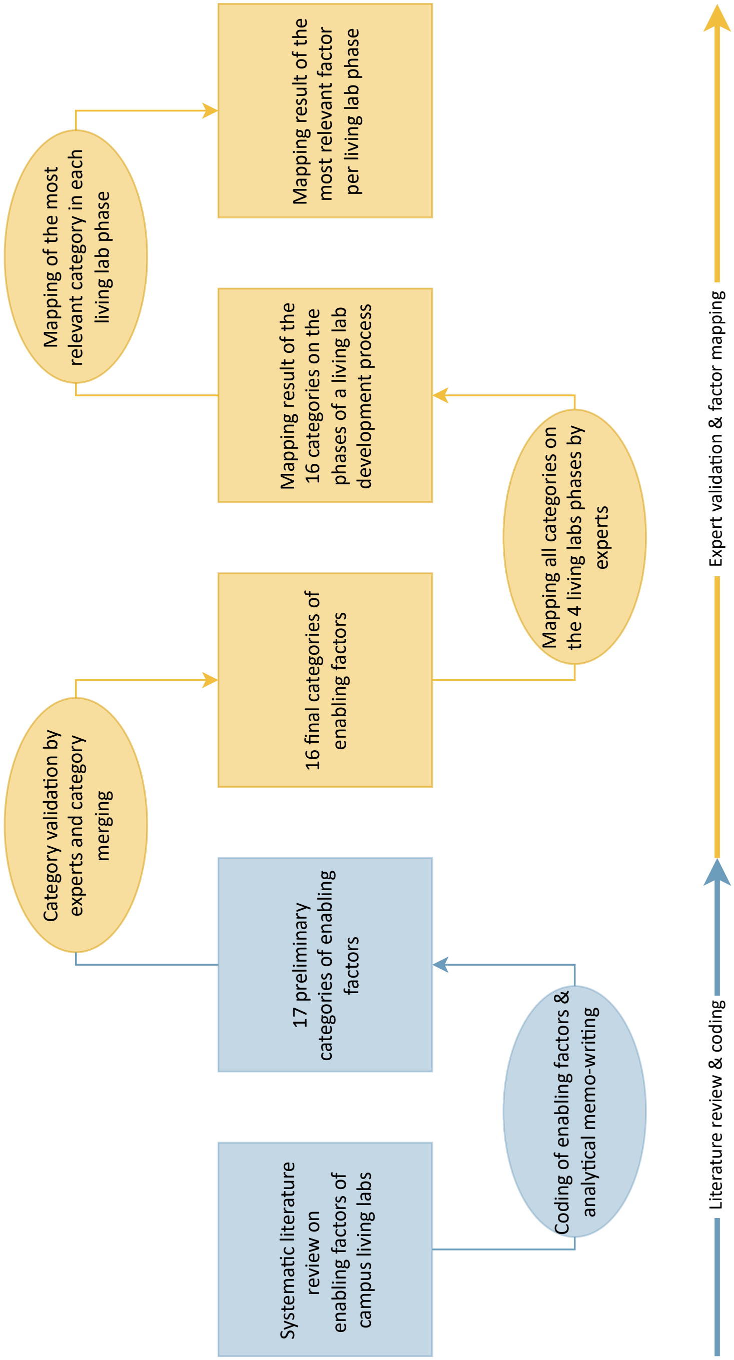

Figure 4-2: Methodological process steps - overview

Third, upon reviewing the initial outcomes of the mapping session, it became clear that a follow-up round would be valuable for interpreting the results. In a subsequent validation step, we asked the same participants to map only the most crucial factor in each phase to assess agreement and identify any prominent factors.

4.3 FINDINGS

4.3.1 Enabling factor categories

Before presenting our results, we first clarify how living labs were understood in our data sample. We observed varying interpretations of living labs across different articles during the analysis. For example, Yusoff et al. (2021) emphasize the various opportunities presented by living labs, including participation, bridging research, operations, and management, involving students, and transboundary intra- and extra-organizational collaborations, all of which impact teaching practices, novel methodologies, and organizational sustainability transitions. Another perspective describes living labs as temporary entities for single activities or formal organizations like research units or hubs that engage in internal and external collaborations (Tercanli & Jongbloed, 2022). For others, they represent the ongoing maturation of university sustainability initiatives (Vargas et al., 2019). However, most articles perceive living labs as a means or tool to drive sustainable innovation and organizational sustainability transitions. Gomez and Derr (2021, p. 7) state: "(…) the living laboratory framework was often applied as a tool to generate new ideas about how to enact sustainability in a local context and to engage students in the process of innovation and ideation." Similarly, Purcell et al. (2019, p. 1354) underline the potential for broader institutional change, stating that "the 'living lab' framework can become a part of transformative institutional change that draws on both top-down and bottom-up strategies." However, there is a need to know how to facilitate that potential.

We analyzed this by coding stated and experiential values in the selected articles using trigger words such as "success factor," "key to success," "key elements," "precondition," "contribute to success," "suggest," "recommend," "important factor," and "facilitating factor." However, most of these terms lacked clear descriptions or definitions, with only one article defining "key performance factors" (van Geenhuizen, 2018, p. 1285). The absence of consistent definitions introduces an interpretation margin and leads to coding stated enablers, as factors were not measured or validated in the articles analyzed.

We identified sixteen non-mutually exclusive enabling factor categories across our sample, underlining categories' interconnection and interdependence. Table 4-1 presents these factor categories, such as Leadership, Learning, and Work Culture, together with their detailed descriptions compiled from the articles' Staying close to the data allows for a more specific understanding of their content and avoids additional layers of interpretation. Notably, fundamental characteristics of living labs, such as co-creation and stakeholder inclusion, are enabling factors in themselves, underscoring the importance of effectively facilitating these aspects.

Table 4-1: Description of categories of enabling factors as identified during the analysis (alphabetical order)

Enabling factor category	Description
Bridging	Bridging the two university internal worlds – namely faculty and operational departments. It also concerns connecting to students and courses.
Collaboration & Co-creation	Effective collaboration in this context involves: · stakeholders and users engaging in transdisciplinary collaboration · within a shared governance space · focusing on a common purpose and vision · building trust and closeness among stakeholders · respecting shared goals and interests · addressing community-owned challenges · implementing ethics committees and privacy protocols · and encouraging student and academic involvement in campus living labs.
Competences & Skills	Developing competencies and skills for living labs, such as conflict resolution, adaptability, continuous learning, capacity-building for various stakeholders, fostering relationships and communities, aligning motivations and capabilities, and specialized management skills.
Coordination	University-wide coordination and oversight of living labs involving organizational structures, multi-stakeholder committees, strategic documents, clear roles and mandates, thematic clustering, project networking, project pipeline generation, capacity matching, review processes, interdisciplinary teams, technology selection, issue forecasting, change management, and incentive creation.
Environment	Selecting locations where real societal problems occur, with necessary logistical and ICT infrastructure, while fostering a creative learning environment and hosting living labs within stable organizations (like universities).

4

Table 4-1: Continued

Enabling factor category	Description
Evaluation	Establishing comprehensive risk assessment and evaluation processes, encompassing technical, sustainability, and alternative criteria tailored to the living lab's focus. It also highlights the need for continuous evaluation, adjusting academic evaluation criteria to include sustainability and transdisciplinary research, and ensuring the dissemination of results, impacts, continuity, and learning.
Funding	Receive continuous and early (co-)funding for feasibility, project management, due diligence, and evaluation, aiming for the self-sustainability of the living lab.
Internal management (of the living lab)	Improving communication among stakeholders, identifying and sharing everyone's expectations and needs, keeping all parties informed about processes and key decisions, ensuring equal participation in co-creation, having the flexibility for resource allocation, prioritizing sustainability and innovation, and managing processes to achieve desired outcomes.
Leadership	Leadership action aligned with a shared vision, including both strong and flat leadership styles while reducing competition among living lab participants, and recognizing leadership contributions from students and stakeholders.
Learning	Providing more learning opportunities, gathering stakeholder input, promoting inter-organizational learning, involving skilled users, and enhancing students' creative and innovative real-world experiential learning experiences.
Methods & Practices	Various tools, methods, and practices used by campus living labs, including open communication, multidisciplinarity, setting up innovation processes, overcoming bureaucratic barriers, balancing freedom and frameworks, defining problems clearly, hosting idea contests, carrying out stakeholder analyses, creating decision-making tools, stakeholder engagement events, online platforms for collaboration, and maintaining flexibility in processes.
Shared understanding	Stakeholders have a clear, commonly owned living lab vision, a shared purpose, and an understanding of the living lab project. Sustainability and transdisciplinarity are key concepts. Stakeholders use consistent language, share a goal, and foster mutual trust.
Stakeholders & Network	Involving all relevant stakeholders from the beginning, avoiding imbalance or excessive dependency, excluding those who might compromise core values, forming a university committee, engaging knowledgeable experts, fostering early public consultations, participating in relevant networks, creating communities of interest, and strategically selecting partners.

Table 4-1: Continued

Enabling factor category	Description
Strategic alignment	Refers to an integrated approach of strategic alignment and anchoring of Living Labs in HEIs' strategies to address campus issues and promote sustainable development (e.g., university's objectives, innovation- and sustainability strategy, real estate, ethics, vision, mission, and curricula).
Transferability & Scaling	Making initiatives more visible internally and using monitoring systems to gather data for researchers and similar buildings to transfer solutions, focusing on universal solutions for implementation beyond universities, sharing knowledge with other organizations, using formal structures for scalability and commercialization, aligning with Sustainable Development Goals (SDGs), building strong relationships with cities, presenting research findings to the right audience, and involving a diverse group of actors for scaling and market acceptance.
Work culture	Fostering a culture characterized by flexibility, agility, openness to new approaches, support from top management, interdisciplinary collaboration, open communication, and a willingness to embrace improvements suggested by living labs in the organization.

4.3.2 Document analysis regarding the sixteen enabling factor categories

We conducted a document analysis to dive deeper into the origins of the factors and determine their relevance. This was done in two ways. First, we considered the different methods employed in the articles to determine if certain enabling factors more frequently appear in articles using particular methods. For that, we divided the sample into case studies (9 articles), and literature reviews and mixed-method studies (combining literature review and case study) (10 articles); two articles used other methods and were disregarded. In the latter ones, living labs served as the framework for investigating research questions unrelated to living labs. To assess the significance of this methodological distinction for our categories, we plotted the count of mentions of the categories from the case studies against those from the literature and mixed-method articles to identify any linear relationship. Indeed, it revealed a difference, as the plot was scattered.

The most striking difference could be seen in the category Coordination, which was extensively discussed in the case studies. Funding also received more attention in the case studies. On the contrary, Stakeholders & Networks and Competencies & Skills were more prominently discussed in the literature review and mixed-

Table 4-2: Results of the document analysis; one dot representing a mention, and two dots indicating a mention in the conclusion and/or abstract

	Burbridge & Morrison 2021	Callaghan & Herselman 2015 *	Du Preez et al. 2022	Evans et al. 2015 *	Gomez & Derr 2021	Kilkis 2017 *	Leal Filho et al. 2022	Lough 2022	Martek et al. 2021	Martinez-Bello et al. 2021
Stakeholders & Network	●●		●●	●●			●●	●		
Coordination		●	●●	●						
Work Culture		●	●●	●			●●		●	
Co-Creation & Collaboration		●●	●●	●			●●			
Methods & Practices		●		●		●●	●	●●	●	
Strategic Alignment	●		●	●	●●		●●		●	
Transferability & Scaling				●			●		●	●
Funding		●●								
Shared Understanding		●			●●				●	
Bridging			●●		●●					
Environment		●		●					●	
Learning							●●			
Competencies & Skills										
Evaluation				●						
Leadership		●●								
Internal Management (LL)			●							

method studies. This suggests that practical issues surrounding campus living labs are primarily addressed in case studies (e.g., coordination, co-creation, strategic alignment, and funding). In contrast, more conceptual topics are emphasized in literature and mixed-method studies (e.g., stakeholders, competencies and skills, work culture, and environment).

Purcell et al. 2019 *	Rivera & Savage 2020 *	Save et al. 2021 *	Sker & Floricic 2020	Tercanli & Jongbloed 2022	Van den Heuvel et al. 2021	Van Geenhuizen 2018	Vargas et al. 2019 *	Westerlund et al. 2018	Yusoff et al. 2021 *	Zen 2017 *	Totals
●		●	●●	●		●				●	16
●		●	●	●	●				●●	●●	13
●		●		●	●	●				●	13
●				●	●	●●					12
		●	●	●	●	●					12
●		●		●							11
●		●		●	●	●●					10
●		●		●	●				●●	●	9
●		●		●	●						8
●										●	6
				●	●	●					6
●						●●				●	6
				●	●	●●				●	5
		●		●		●●					5
●				●	●						5
		●			●						3

Second, we analyzed the most frequently discussed enabling factor categories across all articles to identify the more significant ones. Using a binary system, each category was assigned one point when mentioned in an article and two points when mentioned in the abstract or conclusion, indicating increased relevance. The results reveal the most discussed categories in academic literature, suggesting their importance. For validation, we also generated a table indicating whether factors were mentioned or not without weighting. Comparing the top categories above the median, we found consistent results, with only slight changes in order. This confirms that the top five categories in both results—Stakeholders & Network, Coordination, Work Culture, Co-Creation & Collaboration, and Methods & Practices—are the most frequently discussed and emphasized in abstracts and conclusions (refer to Table 4-2).

4.3.3 Deep-dive into the five most mentioned factors

The document analysis revealed the primary categories discussed in the literature yet lacked indication of depth and breadth. Put differently, it does not cover the full range of points within each category. For instance, while Internal Management was only mentioned in three articles, it encompasses various aspects. Here, we delve into the top five categories to uncover their specific contents. Generally, these categories rather cover the "soft skills" of factor categories and general attributes of living labs, such as co-creation, collaboration, and stakeholder involvement. This might lead to friction in the rather traditional organizational setting of HEIs until new working practices are firmly established.

Stakeholders & Network

A diverse set of relevant stakeholders (internal and external) with different expertise areas should be engaged (Leal Filho et al., 2022), together with knowledgeable experts and knowledge brokers (Du Preez et al., 2022). All relevant stakeholders, including users, should be involved from the start (Tercanli & Jongbloed, 2022; van Geenhuizen, 2018). However, van Geenhuizen (2018) also draws attention to keeping an eye on balance and avoiding too many diverse actors, one stakeholder dominating others, and strong interdependencies between actors. Actors that might endanger maintaining the living lab's core values should also be avoided (van Geenhuizen, 2018). Next, participation in several networks is essential for campus living labs partnerships: Student and user networks, sustainability networks and communities, and the broader innovation ecosystems (Burbridge & Morrison, 2021; Lough, 2022; Tercanli & Jongbloed, 2022). Also, early and proactive public consultation processes and public engagement should occur (Lough, 2022; Save et al., 2021). This goes hand in hand with creating communities of interest around specific problems or topics, which is considered effective towards real-world impact (Burbridge & Morrison, 2021; J. Evans et al., 2015). According to Zen (2017), an HEI-internal committee with key stakeholders, including the top management, academics, operational staff, students, and other relevant campus organizations, should be set up to strengthen the support base and engagement and increase a sense of belonging. All in all, to choose the right stakeholders and networks, a strategic selection process should be in place (Save et al., 2021) while focusing on prioritizing the (social) purpose of organizations and incentivizing public engagement and collaboration (Lough, 2022).

Coordination (at the HEI level)
This category addresses strategic coordination and oversight of campus living labs on an HEI-wide level. It includes the organizational structure for the living lab coordination and a single coordination and information point, often the sustainability office (J. Evans et al., 2015; Purcell et al., 2019; Save et al., 2021; Zen, 2017), with a clear vision for sustainability and innovation on campus (Callaghan & Herselman, 2015; Du Preez et al., 2022). Further, creating a tailored living lab approach setup and defining process phases is vital (Sker & Floricic, 2020), as well as setting up a governance model and ensuring the availability of human resources and strategic documents and related processes (Save et al., 2021). All while drawing on both top-down and bottom-up approaches (Purcell et al., 2019; Zen, 2017). Clear roles of campus managers, mandates (Du Preez et al., 2022), and transparent administrative procedures are required. As is continuous communication with partners (Tercanli & Jongbloed, 2022). Connected to good communication is making the campus living labs visible and showcasing their impact on the SGDs on the institutional level (Purcell et al., 2019).

It also includes being strategic about review proposals, having an interdisciplinary business case review team, developing selection criteria, strategic decision-making tools, a list of technology for implementation, success metrics, reporting processes, forecasting campus issues, and developing work plans to deal with them (Callaghan & Herselman, 2015; Save et al., 2021). The coordination body should support capacity building; if funding is unavailable, this can also be done by, e.g., developing guidelines and training material (Callaghan & Herselman, 2015). Equally, generating a pipeline of living labs projects (J. Evans et al., 2015) and matching projects with capacities and operational systems (Zen, 2017) should be ensured. Thematic clustering of living labs (Zen, 2017) and inter-project networking opportunities (Callaghan & Herselman, 2015) can help here. Also, a change management team, including all HEI stakeholders (Purcell et al., 2019), champions throughout the organization, and a multi-stakeholder committee structure for decision-making (Save et al., 2021) should be implemented.

Work Culture
This category relates to the way of working and the work culture in campus living labs and the HEI organization to enable them. There is a role for HEIs to support multi-disciplinary approaches, including administratively, with their organizational structures and top management (Callaghan & Herselman, 2015; J. Evans et al., 2015; Leal Filho et al., 2022; Zen, 2017). Likewise, experimentation for sustainable solutions in living labs should be encouraged (Purcell et al.,

2019). To that end, "room to maneuver" needs to be granted and supported regarding finances, project- and risk management, and human resources (Du Preez et al., 2022). This room needs to extend to designed serendipity (meaning the room for unexpectedness, discovering unforeseen findings and insights while adding value), which is generally embraced by the living lab approach (van den Heuvel et al., 2021). Martek et al. (2022, p. 8) state bluntly: "(…) for living labs to be successful, there must be a means to insulate them from the stultifying impact of university bureaucracy." Of course, HEIs need to be open and ready to accept and incorporate resulting suggestions from the living labs (Zen, 2017). Equally, commitment from academics to work outside their administrative and disciplinary channels is required (J. Evans et al., 2015). As is a strong interest from academics and students in sustainability and living labs (Tercanli & Jongbloed, 2022). Living labs on campus require a matching work culture that is characterized by high flexibility, informality, result orientation, and intentional action (Du Preez et al., 2022; Martek et al., 2022; van den Heuvel et al., 2021), a win-win and work-smarter-not-harder mentality (van den Heuvel et al., 2021), open communication (Leal Filho et al., 2022), and supporting each other in network settings (Callaghan & Herselman, 2015). They also require respect for essential values like sustainability and the social values of all stakeholders (van Geenhuizen, 2018).

Co-Creation & Collaboration

This category includes the collaboration of stakeholders and users in transdisciplinary ways, which calls for a shared governance space that can take the form of a living lab (Purcell et al., 2019). In general, the living labs are integrated directly into the work on campus (J. Evans et al., 2015), which inherently requires collaboration from internal and external stakeholders, central to the co-creation process of living labs (Purcell et al., 2019). The collaboration needs to be inevitably based on agreement and trust (Leal Filho et al., 2022; van den Heuvel et al., 2021) and a sense of closeness between the living lab stakeholders (internal and external ones) (van den Heuvel et al., 2021). This requires respecting shared goals and interests and a sense of community-owned challenges addressed in the living lab (Callaghan & Herselman, 2015; van Geenhuizen, 2018). Participants and living lab managers should be able to detect and respond to opportunities, successes, and challenges related to the participants, stakeholders, the wider community, and living lab activities (Callaghan & Herselman, 2015). Needed skills should be developed, e.g., for conflict handling and intermediation, with an eye on shared goals and interests (see also category Competencies & Skills) (Callaghan & Herselman, 2015; van Geenhuizen, 2018). The presence of an ethics committee and privacy protocol should be considered (Tercanli & Jongbloed, 2022). Co-creation in campus living labs needs a shared purpose and vision (Callaghan & Herselman, 2015; Purcell et al., 2019; van den Heuvel et al., 2021). Even the vision should be co-created to be commonly owned (Callaghan & Herselman, 2015). In general, the engagement and involvement of users is vital to campus living labs (see also Stakeholders & Network) (J. Evans et al., 2015; Leal Filho et al., 2022; van den Heuvel et al., 2021). In the context of HEIs, this might also concern students. As is a bottom-up push from students and academics (Tercanli & Jongbloed, 2022).

Methods & Practices

This category includes tools, methods, and practices that enable campus living labs, sometimes presented as best practice examples. The more general ones are the promotion of open communication and multidisciplinarity (Leal Filho et al., 2022), the use of multiple approaches and tools (van Geenhuizen, 2018), the application of innovation processes (Callaghan & Herselman, 2015), getting around bureaucratic barriers for innovations (Lough, 2022), and finding a balance between “freedom and framework” (van den Heuvel et al., 2021, p. 36). This also translates into keeping flexibility in processes, balancing formalization, and not over-formalizing to stay true to the nature of living labs (Save et al., 2021).

There are also a number of more concrete enablers, like: Breaking down complex questions into complementary projects by taking a systems approach (J. Evans et al., 2015), exact definition and analysis of the problem to solve (Sker & Floricic, 2020), idea generation practices to anticipate stakeholders’ challenges and opportunities (Callaghan & Herselman, 2015), preparations to timely dealing with vulnerable users (van Geenhuizen, 2018), development of a process roadmap with action steps (Save et al., 2021), hosting contests for ideas and linking feasibility studies to them (Save et al., 2021), broadscale stakeholder analyses (Martek et al., 2022), development of strategic decision-making tools (Save et al., 2021), living lab project categorization based on size for overview (Save et al., 2021), hosting a kick-off event with all stakeholders (Save et al., 2021), having a “door-opener” to connect with communities (Tercanli & Jongbloed, 2022), launching a living lab website to search and connect people and projects (J. Evans et al., 2015), map and identify researchers across campus (Kılkış, 2017) and selecting research champions (Save et al., 2021), physical and virtual communication and interactions (Callaghan & Herselman, 2015), use of social media tools for stimulation (van den Heuvel et al., 2021), and regular face-to-face interaction (Callaghan & Herselman, 2015; van den Heuvel et al., 2021). Also, engagement with active sustainability communities ready for involvement can be beneficial (Tercanli & Jongbloed, 2022).

4.3.4 Salience of factors across living labs' development phases

Having extracted enabling factor categories from the literature, our next objective was to determine their relevance across the development stages of a living lab. The existing literature has outlined various process- and development phases (e.g., Bergvall-Kåreborn & Ståhlbröst, 2009; Martek et al., 2022; Save et al., 2021; Steen & van Bueren, 2017). We synthesized these into four aggregated process phases. We emphasize that they are not to be perceived as static stage-gate processes but as iterative and dynamic phases with feedforward- and feedback loops, as depicted by the looped arrows in Figure 4-3.

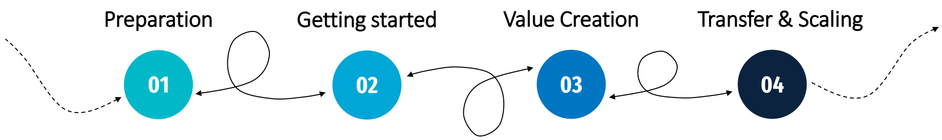

Figure 4-3: Development phases of living labs

The development process of a living lab is essentially ongoing, with knowledge transfer and scaling potentially leading to new research inquiries and the establishment of further living labs, thus restarting the cycle. The phases are not as clearly delineated in reality, especially in fluid settings like living labs. The initial phase, preparation, precedes the launch of the campus living lab and involves tasks such as assessing available competencies, identifying key stakeholders, and aligning on values, issues, and potential impacts. Following this is the getting started phase, where practical aspects like assigning roles and mandates, setting up infrastructure, and defining objectives occur. Next, the value creation phase is marked by active co-creation for innovation, accompanied by continuous evaluation. The final phase, transfer and scaling, involves embedding, translating, or expanding the living lab's outcomes and knowledge, including tangible results and insights garnered throughout the preceding phases (Wirth et al., 2019).

The expert mapping sessions yielded two types of results. To recall, experts were asked to map factor categories onto the living lab phases they considered most pertinent, with an option to indicate if a factor applied across all phases (see Appendix G for exemplary results). First, we compared the top categories from the literature review with the experts' opinions. In our analysis, we considered categories mapped across multiple phases more relevant. Indeed, this approach revealed a different ranking of the top five categories compared to the literature review. Notably, Learning, which ranked low in the literature review, emerged as a top factor in the expert ratings, sharing first place with Stakeholders & Networks, while Methods & Practices dropped to the bottom (see Table 4-3).

Table 4-3: Results of the expert mapping of the categories on the living labs phases, color-coded and sorted by sum of points per category. The top five from the literature review are marked with a star.

	01 - 04 Across all phases	**01 Prepa-ration**	**02 Getting started**	**03 Value creation**	**04 Transfer & scaling**
Stakeholders & Network *	5	6	6	5	5
Learning	4	4	6	6	6
Shared Understanding	4	5	7	5	4
Internal Management (of the LL)	4	4	6	7	4
Co-creation & Collaboration *	4	4	6	6	4
Evaluation	4	4	4	6	6
Leadership	3	7	4	4	4
Work Culture *	3	6	6	4	3
Coordination *	3	6	5	4	3
Environment	2	6	3	5	3
Bridging	2	4	3	3	5
Competencies & Skills	2	5	3	4	3
Funding	1	6	2	3	4
Transferability & Scaling	0	4	1	1	6
Methods & Practices *	0	1	4	5	1
Strategic Alignment	0	4	2	2	2
Color legend	0 - 2				
	3 - 4				
	5 - 7				

Second, the mapping results enabled us to identify trends in the relevance of categories across specific phases or throughout the development process of a living lab. Certain categories were deemed particularly relevant during specific phases, while others were considered crucial across all phases (see Table 4-3). Of course, the table can be read in two ways: by column or by row. Column analysis reveals which factor categories are pertinent to specific phases, while row analysis illustrates the evolving relevance of categories during the living lab process. Given the aim of enabling living labs tailored to their phase, we proceed by column. In the following, we first present the highly relevant categories throughout all phases, then focus on the top five from the literature review, and last, emphasize those categories that stand out per phase.

Firstly, we draw attention to the “Across phases” column, which deserves separate consideration despite being integrated into all other columns via point distribution, as it highlights factor categories deemed consistently relevant during all phases by the expert panel. The factors are crucial throughout the entire development process of campus living labs and diverge from the top five identified in the literature. Notably, Stakeholders & Network, Learning, Internal Management, Shared Understanding, Co-Creation & Collaboration, and Evaluation, all assigned by most experts, underscore the significance of living labs’ foundational inner workings throughout all phases. Particularly, Stakeholders & Networks stand out, complementary to the findings in the literature and underlining this factor’s overall relevance. Contrary to the scientific discussion’s focus, Learning and Evaluation also gain relevance when concerning phases. Generally, Stakeholders & Networks and Shared Understanding remain highly relevant from the first phase onwards, with the latter declining in relevance during the transfer and scaling phase. Learning gains significance as phases progress to operational and scaling stages. Internal Management, Co-Creation & Collaboration, and Evaluation’s relevance increase during operational phases two and three. Evaluation also remains highly pertinent in the last phase.

The top five categories of the document analysis (marked with a star in Table 4-3) exhibit varying dynamics. As Stakeholders & Networks play an integral role throughout the entire developmental spectrum, Work Culture and Coordination are particularly crucial in the initial phases until the living lab is fully operational. Then, their need for high-level coordination seems to decrease as they establish their own working cultures. Meanwhile, Methods & Practices and Co-creation & Collaboration gain prominence during the launch and operational phases, hinting at their significance in living labs’ practical value-creation processes.

Phase 1

In the preparation phase, unanimously *Leadership* stands out as highly relevant. This is unexpected in light of the little attention the category received in the literature. However, the factor might also be seen in relation to creating momentum for the living lab to start, ensuring a *Shared Understanding*, and creating suitable conditions. Connected to the latter are also *Stakeholders & Network*, *Competencies & Skills, Work Culture, Coordination*, and *Environment*, all deemed especially relevant during this phase. Unsurprisingly, *Funding* is also highly relevant in securing the financial means for starting a living lab.

Phase 2

The start phase underscores again the high importance of a *Shared Understanding* of *Stakeholders & Networks***.** Besides, some more operational factors gain relevance, such as *Internal Management, Co-creation & Collaboration*, and *Coordination*, all underpinned by a conducive *Work Culture*. *Learning*, as mentioned previously, also emerges as vital from the start.

Phase 3

During the value-creation phase, *Internal Management* is seen as most relevant (despite having received the least attention in the literature), alongside the more operational factors mentioned in Phase 2, such as *Shared Understanding*, *Co-Creation & Collaboration, Stakeholders & Network,* and *Learning*. As living labs are starting, their previous needs for coordination and establishing fitting work cultures seem to decrease, while a suitable *Environment*, and employing appropriate *Methods & Practices* are becoming more relevant.

Phase 4

In the final transfer and scaling phase, the factors of *Learning, Evaluation*, and *Transfer & Scaling* take precedence. For the latter to happen, *Stakeholders & Networks* are relevant, alongside *Bridging* to extend opportunities to other stakeholders and contexts.

4.3.5 Validation of the mapping results

We assessed interrater agreement to determine if the expert panel's factor mapping reflected genuine consensus or occurred by chance (Gisev et al., 2013; Nichols et al., 2010). Our findings showed Fleiss Kappa values close to zero (positive) for each phase (refer to Appendix H). This indicates slight agreement among raters beyond chance expectations (Landis & Koch, 1977). Therefore, the mapping results suggest first tendencies rather than absolute statements, indicating that living lab experts hold divergent views on the specific relevance of factors across phases.

After the initial mapping round, we asked the same experts to identify the single most relevant factor category per phase, limiting their choice to one factor compared to the previous round. The aim was to determine if one particular factor category was more consistently deemed critical in specific phases. However, the results showed even greater divergence. Through discussions and explanation rounds, we concluded that the experts' disciplinary lens and concrete living lab experiences strongly influenced their responses. Nevertheless, despite the varied perspectives, the underlying motivation for their choices consistently pointed towards the potential emergence or development of factors when living labs operate smoothly. This argumentation points to the living lab's resilience if some factor categories exist while others might not be critical. For instance, some experts suggested that successful living labs might naturally transfer and scale due to their extensive stakeholder networks. While this argumentation holds for some factors, previous research has shown that transfer and scaling remain significant challenges for campus living labs if not initially integrated into planning processes (Herth, 2024b).

4.4 DISCUSSION

4.4.1 General discussion of process and findings

Our study aimed to uncover enabling factors for campus living labs throughout their development. The mere presence of all enabling factor categories in the literature inherently suggests their relevance, albeit with some receiving more attention than others. However, we establish an order of relevance through the document analysis and the phasing of categories. Notably, the category of Stakeholders & Networks stands out as highly relevant in both analyses, emphasizing the importance of careful stakeholder involvement and maintenance throughout all phases. Also, Co-Creation & Collaboration, another fundamental characteristic of living labs, surfaced as vital in both analyses. However, differences exist between the identified factors in the document analysis and the phasing. Whereas the document analysis also yielded contextual factors, such as Work Culture or Coordination, the phasing analysis highlights factors related to practical inner workings, such as Shared Understanding, Internal Management, and Learning.

Overall, the inventory of enabling factors underscores living labs' complexity and diverse needs. The non-mutually exclusive factors reflect their interconnectedness and interdependence (see Table 4-1). For instance, Co-creation & Collaboration rely on Stakeholders & Networks. Generally, the factors are not to be understood as prescriptive but as guideposts for campus living labs and their environment, which need adaptation to various contexts and circumstances. This aligns with findings from similar studies on success factors that found interdependencies and point to the need for adaptation to specific contexts (Bergmann et al., 2021). Additionally, some factors are inherent attributes of living labs, as noted in other studies (Berberi et al., 2023; Bergmann et al., 2021). Despite overlapping categories, our dataset demonstrates coherence as the factors depict the characteristics, requirements, and complex interdependencies for well-functioning living labs.

Contextualizing cross-case enabling factors by specifying their evolving relevance across living labs' developmental phases enhances understanding of their varying needs throughout different stages, contributing to the living lab literature. While process phases have been acknowledged in campus living lab literature (Martek et al., 2022), there has been a lack of specificity regarding considerations for these phases, a gap we address with our findings. We suggest that by better understanding living labs' phase-specific needs, we partly unravel their complexity and enable more effective and tailored facilitation. This, in turn, complements and advances previous case-specific studies (analyzed in our study), investigations of challenges, and the emerging field of living labs within higher education contexts (van den Heuvel et al., 2021). Practically, our study's findings enable HEIs, living lab coordinators, and practitioners to create favorable conditions for flourishing living labs on their campuses while leveraging them to drive sustainable innovations for broader transitions. The identified enabling factors and their phased approach can serve as a navigation guide to focus facilitation efforts on the most critical areas.

To steer these efforts, the mapping exercise (see Appendix G) emerged as a tool with two potential applications. Firstly, it can be utilized as input for living lab coordinators and stakeholders to clarify phases and enabling factors, fostering a common understanding, managing expectations, and reducing uncertainty in the living lab process. Secondly, it can facilitate internal discussions, decision-making, and project management, revealing different understandings and expectations, clarifying stakeholder roles and mandates, and addressing leadership questions across different tasks or phases. The expert discussions highlighted the mapping exercise's value as an adaptable discussion tool for elaborating and refining the status quo in various campus living labs and phases rather than as a top-down input to establish a predefined one. This approach resonates with the dynamic and context-specific nature of living labs. Therefore, regular revisions and re-establishment of the initial mapping result, co-created with all living lab stakeholders, are essential to incorporate new insights and ensure ongoing alignment. As such, the mapping can serve as a tool for reflection and evaluation. One panelist has already intended to adapt the mapping exercise for their institution, incorporating sticky notes for actors and tasks.

4.4.2 Limitations and future research

This study's limitations concern the database, coding, and mapping processes. The database was drawn from only two sources, considered to reflect the scientific literature comprehensively, but restricted the sample to English-language peer-reviewed articles. Next, our analysis did not account for specific campus contexts, potentially overlooking cultural influences or alternative worldviews. Future research could investigate those contexts to uncover additional enabling factors. Efforts were made to mitigate potential biases in the interpretation and clustering of codes through internal and external discussions. However, further research should provide more detailed descriptions of enabling factors to avoid such biases in future studies and provide actionable insights.

The phase-specific results, derived from a small group of experts, could benefit from validation through repetition with a larger participant group and diverse stakeholders. We found that the mapping outcomes are influenced by experts' disciplinary backgrounds and experience, suggesting that narrower selection criteria may yield clearer results. However, living labs' transdisciplinary nature suggests that restricting the expert group could misrepresent their functioning. Likewise, further development of the mapping tool, such as integrating actors, responsibilities, and tasks, may be practically beneficial in creating a shared understanding and reflexivity in the different living lab initiatives. Applying and adapting the tool in use cases may further its generalizability. Future research should consider living labs' phase-specific needs when developing governance and management approaches while integrating enabling factors. More research is needed, particularly through cross-case analyses, to better understand the pathways of on-campus living labs.

As our enabling factor categories are overlapping and interdependent, we suggest conducting a factor analysis, which was not carried out in this study. We also discussed how enabling factors could support the resilience of campus living labs, even if not all factors are present, as others may emerge naturally. Future research could investigate the critical factors for each phase and identify tipping points. Additionally, a point often overlooked, or at least not published, is failed cases (Bauwens et al., 2023; Fanelli, 2010; Turnheim & Sovacool, 2020). However, they could reveal which enabling factors were lacking in which phase, validating or refuting the findings of this study.

4.5 CONCLUSION

Current studies have not yet offered general insight into the enabling factors for campus living labs across the scientific literature. This study addresses this gap by providing an inventory of relevant factors, highlighting their complexity and interdependence, and offering detailed insights into the most pertinent ones: stakeholders, coordination, co-creation and collaboration, work culture, and inner work practices within campus living labs. Prioritizing the inventory of factors throughout their development phases may enable contextualization and more effective catering to their phase-specific needs. Although our study does not allow for firm statements yet, due to a small sample size and modest participant agreement, we can conclude some trends for the factor's relevance in those phases. In the first phase, especially leadership, coordination, the relevant stakeholders, a conducive environment and work culture, and funding are crucial enablers for initiating a living lab. As it progresses, operational phases highlight the importance of shared understanding, internal management, stakeholder co-creation and collaboration, appropriate methods and practices, and evaluation and learning. Finally, transfer and scaling, evaluation and learning, and bridging stakeholders and contexts enable the dissemination of outcomes and insights.

A better understanding of these dynamics might also aid the factors' application in practice, offering guidance for Higher Education Institutions to actively support the facilitation process and create suitable conditions for campus living labs to flourish, literally "in their front yard." Additionally, the results provide method-driven guidance for campus living lab coordinators and participants to tailor their facilitation efforts to the specific development needs. Here, our set of factors serves as a starting point, highlighting areas for focus while emphasizing the need for adaptation to specific local contexts. The mapping exercise can facilitate internal discussions and reflections, fostering a common understanding among stakeholders. By leveraging their capacities and resources more efficiently, HEIs, coordinators, and practitioners can enable the contexts to drive sustainable solutions for the complex societal challenges of our times and the future.

In the previous chapters, we explored the opportunities, challenges, and enabling factors of on-campus living labs to create suitable conditions for them to innovate successfully. We also emphasized that effective organization-wide coordination and deep organizational integration within Higher Education Institutions are critical yet complex tasks. As such, there is a growing demand for concepts and tools to support Higher Education Institutions in progressing from facilitating single initiatives to the more comprehensive "Campus as a Living Lab" approach. This chapter introduces and develops the concept of the "Campus as a Living Lab," distinct from standalone "Living Labs on Campus." We clarify the iterative process phases and propose a tool to support the launch of the Campus as a Living Lab, adaptable to Higher Education Institutions' diverse contexts and settings. With the results of this chapter, we contribute to clarifying different approaches to how Higher Education Institutions can leverage their campuses and living labs to facilitate sustainable transformations, contributing to broader societal impacts beyond their institutional boundaries.

Chapter 5

From Living Labs on Campus to the Campus as a Living Lab

A tool to support the sustainability transformation of universities

A previous version of this chapter was accepted for publication as:
Herth, A., Vogel, N., & Bossert, M. (in press) From Living Labs on Campus to the Campus as a Living Lab – A Tool to Support the Sustainability Transformation of Universities. In W. Leal Filho, J. Newman, A. Lange Salvia, & L. Viera Trevisan (Eds.), North American and European Perspectives on Sustainability in Higher Education: World Sustainability Series. Springer.

Spelling and formatting have been aligned throughout the dissertation.

ABSTRACT

Higher Education Institutions possess significant potential to tackle today's complex societal challenges by using their innovation capacity and vast resources. Living labs, already established on campuses worldwide, offer a promising avenue for leveraging this potential. However, a comprehensive understanding of their implications and implementation requirements is needed, especially when HEIs aim to harness their sustainable transformation potential structurally beyond single initiatives. As such, there is a growing demand for concepts and tools to facilitate a shift from individual living lab initiatives to a more comprehensive approach. Responding to this demand, this chapter aims to support Higher Education Institutions in establishing the Campus as a Living Lab. Drawing on insights from an international Community of Practice, existing literature, and case studies, we conceptualize the "Campus as a Living Lab," distinct from individual on-campus living lab initiatives. This approach is comprehensive, connected, and firmly embedded, striving to create synergies, knowledge exchange, and cross-fertilization among various campus innovation initiatives. The entire campus and the organization serve as a fertile ground for sustainable experimentation and innovation. Further, we outline the initial development process and provide a tool for launching the Campus as a Living Lab, adaptable to diverse contexts. During the preparation phase, key elements include analyzing the current landscape of campus initiatives, co-creating a shared vision, mapping competencies, and considering governance structures. The actual start phase focuses on practical implementation, involving the development of vision and mission statements, establishing those governance structures, performing foresight assessments, and fostering a supportive work culture. Both phases emphasize co-creation, strategic planning, and engagement to tailor the Campus as a Living Lab to the local context. This chapter encourages Higher Education Institutions to transition from hosting stand-alone living labs to an integrated approach, enabling them to utilize their unique position to contribute significantly to sustainable transformation processes.

5.1 INTRODUCTION

Higher Education Institutions (HEIs) have the opportunity to contribute significantly to speeding up the process of co-creating urgently required solutions addressing climate change and sustainability transformations by working with their faculty staff, students, and their broader stakeholder community (Cortese, 2003; Findler, Schönherr, Lozano, & Stacherl, 2019; Trencher, Bai, et al., 2014). They can help shape new ways of tackling the grand challenges of our times, with the Sustainable Development Goals as a compass (Trencher, Yarime, et al., 2014; United Nations, 2015). In a world often described as having volatile, uncertain, complex, and ambiguous conditions, HEIs are called upon to play a crucial role in identifying and mitigating these risks and co-developing tailored local solutions with affected stakeholders (Purcell et al., 2019). Not only focusing on annual or quarterly turnover or election periods, HEIs have the unique chance to create and follow long-term strategies and plans. As knowledge hubs, they can simultaneously operate on several levels by collaborating with local and regional stakeholders (Leal Filho & Brandli, 2016; Trencher & Bai, 2016; Verhoef et al., 2017), connecting to industry and mobilizing transdisciplinary solutions (Mowery, 2007; Watson-Capps & Cech, 2014), and educating students to become future sustainable leaders (Rosenberg Daneri et al., 2015).

In addition to research and education, the third mission of universities is to contribute to society and distribute knowledge to a wider audience (Compagnucci et al., 2021; Göransson et al., 2022). However, this mission is often translated into "commerciali[z]ing technical products rather than supporting more intangible complex social innovation activities" (Göransson et al., 2022, p. 15). That issue can be addressed by knowledge co-production that transgresses existing system boundaries through open research environments that operate in transdisciplinary work modes (Schneidewind et al., 2016). Transdisciplinary work modes include and honor knowledge from various origins along with scientific knowledge, like practice-based knowledge. Here, HEIs play a key role by providing a knowledge base for learning, serving as visionary platforms, and enabling experimentation to understand mechanisms that may impact societal change (König & Evans, 2013).

In this realm, so-called living labs provide opportunities for HEIs as they combine the expertise of different stakeholders to encourage knowledge application (Leal Filho et al., 2020). Living labs aim to solve complex societal challenges with transdisciplinary developed, co-created innovations. They are set in real-world environments with multi-stakeholder settings (public-private-people partnerships) and actively involve users (Greve et al., 2021; Hossain et al., 2019; Westerlund & Leminen, 2011). Even though HEIs may have a great capacity for hosting and facilitating constellations like living labs, they seem to miss out on using them to their full potential (Lough, 2022). This might be because HEIs encounter numerous challenges concerning implementation, operation, scalability, internal and external boundary-spanning, and complex decision-making structures (Herth, 2024b; Tercanli & Jongbloed, 2022; van Geenhuizen, 2018). Others found that HEIs are rather rigid hierarchical organizations grappling with opportunities for change (Leal Filho et al., 2019; Martek et al., 2022), making it difficult to integrate living labs and their principles of transdisciplinary work modes, citizen involvement, and multi-stakeholder collaboration into the prevailing structures.

Nevertheless, HEI campuses are ideal spaces for living labs due to opportunities for interaction between various stakeholders. Moreover, access to premises and infrastructure for research purposes is relatively easy, and state-of-the-art knowledge and a strong focus on innovation are present. Next to that, HEIs often own large premises, which can provide long-term experimentation space (Leal Filho et al., 2019). Through living labs, HEIs can also showcase their research and prototype sustainability transition pathways within their organizations (e.g., Save et al., 2021).

Hossain et al. (2019) show that there are limited reference models for stakeholders who want to set up living labs, including their development and management. Likewise, HEIs are looking for new reference models since the processes in which on-campus living labs emerge and are managed tend to stay in the dark and need to be better documented (Martek et al., 2022). Some even argue that living labs should not be used as tools for the HEIs, but rather, the entire campus should be used as a living lab (Leal Filho et al., 2022). However, this has far-reaching consequences, transitioning from a rather project-oriented approach (single living labs on campus) to a changed understanding of utilizing the campus and its resources firmly anchored into the organizational structures (the campus as a living lab).

Many HEIs worldwide are working towards the latter approach, aiming to utilize their extensive resources and proclaim to set up the campus as a living lab. For example, the sustainability vision, ambition, and action plan of the Delft University of Technology states that "using the campus as one large laboratory is expected to speed up the experimentation, evaluation and implementation of new solutions that contribute to the sustainable development goals" (van den Dobbelsteen & van Gameren, 2021, p. 52). Even though the report mentions a need to develop a methodology around living labs, governance structures, and employee training, it fails to explain or define the terms living lab and the campus as a living lab. Equally, the sustainability report of Harvard University mentions living labs in the presidential foreword and later as a priority to "work to unlock the campus's potential as a test bed and living lab, incubating transformative new ideas and piloting them on Harvard's campus and with partners" (Harvard Office for Sustainability, 2023, p. 41). However, how this is practically achieved stays unsaid in both cases.

Therefore, we aim to explore how the Campus as a Living Lab can be operationalized and brought into practical use. We intend to clarify the obscure concepts and processes around living labs in HEI contexts and the underlying understandings. This includes enlightening the differences between "Living Labs on Campus" and the "Campus as a Living Lab" concerning their notions, processes, and setup. As we aim to enable HEIs to the less developed but promising concept of the Campus as a Living Lab, we especially concentrate on illustrating crucial steps to set up and get started with that approach. In short, this chapter contributes to conceptualizing the different notions of Living Labs on Campus and the Campus as a Living Lab. Next, it clarifies the process stages of the Campus as a Living Lab approach. Last, we present a heuristic model to support HEIs with actionable steps to start the Campus as a Living Lab.

5.2 THEORETICAL BACKGROUND FOR THE CAMPUS AS A LIVING LAB

The complexities of societal challenges and their contextual embeddedness, plural consequences, and perspectives on solving or coping with them provoke knowledge integration from various research fields and actors outside academia. This demands context-driven, problem-focused, and transdisciplinary knowledge co-production (Nowotny et al., 2001; Polk, 2015). Transdisciplinary research also recognizes and includes knowledge from various disciplinary fields other than scientific knowledge to solve complex and wicked problems. These include practice- and experience-based knowledge and expertise.

One such transdisciplinary setting is living labs. The notion of a "living lab" is becoming increasingly popular and resonates well with open innovation claims to include external stakeholders in the overall innovation process (Chesbrough et al., 2006). A living lab fosters innovative collaboration among stakeholders to solve complex problems requiring transdisciplinary methodologies (Almirall et al., 2012; Westerlund & Leminen, 2011). User-centric approaches encourage innovation through active participation and integrating the knowledge of different users (Eriksson et al., 2006; Leminen et al., 2012). This participation and integration underlines the transdisciplinary character of living labs.

During the last two decades, "living lab" has developed into a term with diverse meanings and is used by researchers in multiple disciplines (Leminen & Westerlund, 2019). According to the existing literature, living labs are an interesting topic offering numerous research opportunities and a novel design, methodology, and tool to solve various complex challenges and address the needs of our time (e.g., Rodrigues & Franco, 2018; Voytenko et al., 2016). There have been quite a few studies on living lab definitions (Leminen et al., 2012), components and principles (Bergvall-Kåreborn & Ståhlbröst, 2009; Westerlund, Leminen, & Habib, 2018), roles (Leminen et al., 2015), and motivations (Bergvall-Kåreborn & Ståhlbröst, 2009). In practice, there is an increasing number of actively operating living labs in diverse settings worldwide, with a high concentration in Europe (McPhee et al., 2017). This chapter focuses on living lab settings in HEI campus environments, not on settings like urban living labs, real-world labs, or sustainability labs (for differences, see, e.g., McCrory et al., 2020; Schäpke et al., 2018).

We view living labs as systematic approaches to innovation characterized by public-private-people partnerships (4P) between businesses, public institutions, HEIs, and users in physical or virtual real-world environments and contexts, collaborating and co-creating new technologies, products, services, and systems (Westerlund & Leminen, 2011). In 4P, the people dimension extends public-private partnerships, which is crucial in living labs, as it ensures the involvement of users and civil society. Our understanding expands and complements the above-mentioned definition's elements with learning, reflection, and change management to accelerate the sustainability transformation.

We consider the Quintuple Helix innovation model (Carayannis et al., 2012) an appropriate foundation since it refers to solution-finding and innovation processes that can address climate change. Where the Triple Helix innovation model focuses on university-industry-government relations (Etzkowitz & Leydesdorff, 2000), the Quadruple Helix extends the model by a civil society helix (Carayannis & Campbell, 2009). The Quintuple Helix model places the Quadruple Helix into the context of the natural environment of societies, which makes it a suitable approach for sustainable development (Carayannis & Campbell, 2010). The five-helix structure's complexity includes interdisciplinary and transdisciplinary structures (see Figure 5-1 from Carayannis and Campbell (2022, p. 72)). All helices must be involved continuously, spanning the entire disciplinary spectrum: from the natural sciences (because of the natural environment) to the humanities and social sciences (because of society, democracy, and economics). It is an underlying innovation model for many living lab approaches. In particular, the physical dimension of the site can impact processes transforming how campuses are organized and perceived.

Since HEIs are set in different contexts that need to be considered (see Quintuple Helix), they cannot be supported by a rigid model that strives for the optimal solution. Instead, they need to be supported by flexible and adaptable structures, such as heuristics. Heuristics are "adaptive tools that ignore information to make fast and frugal decisions that are accurate and robust under conditions of uncertainty" (Mousavi & Gigerenzer, 2017, p. 368). They can also be described as "rules of thumb that do not require complete information search or exhaustive calculation" (Mousavi & Gigerenzer, 2017, p. 367). Thus, they are attractive tools that save effort but still deliver accurate judgments, while their robustness is rooted in their simplicity (Mousavi & Gigerenzer, 2017). The success of a heuristic depends on the match with the context and environment in which it is utilized (see Quintuple Helix). At large, it depends on one's cognition to exploit existing environmental structures and one's ability to deal with error (Gigerenzer & Gaissmaier, 2011). Heuristics can be part of more extensive toolboxes and combined with more optimization-seeking rules, too (Mousavi & Gigerenzer, 2017). This is particularly pertinent when considering the various contexts of HEIs and the subsequent need for an adjusted set of tools in their toolboxes.

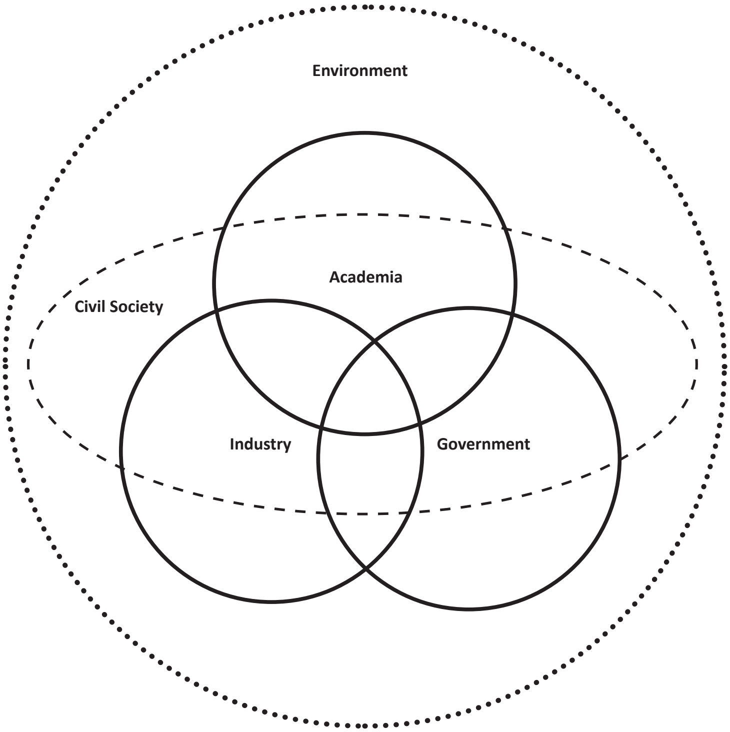

Figure 5 1:The Quintuple Helix innovation model
(Carayannis & Campbell, 2022, p. 72)

Uncertainties and context dependency are inherent in sustainable campus development, so the choice to follow a heuristic allows a more progressive and adaptable engagement than a narrow model that may not fit the HEI-specific circumstances. Therefore, we aim to offer guidance in the early phases of a Campus as a Living Lab approach in an agile and adaptable manner that is consequently locally meaningful.

5.3 METHODOLOGY

We iteratively co-developed and tested approaches and methodologies for the previously identified research gaps, focusing on living labs in the context of sustainability transformation, climate change, and the role of HEIs. We addressed and validated these gaps in a Community of Practice (CoP), at conferences and tailored workshops, and in our own organizations. We applied a fluid three-layered approach comprising external inputs, the author teams' iterative process, and validation (see Figure 5-2). Especially the layers of the author team and validation were iteratively informing and feeding each other. The following paragraphs describe the methodological layers and their interaction in more detail.

The shared goal of gaining deep insights into the theoretical frameworks and practical manifestations of the Campus as a Living Lab called us to draw on the knowledge, perspectives, and experiences of various participants from different backgrounds. CoPs can be understood as social learning systems where participants co-produce knowledge and artifacts while creating a shared history of learning (Wenger, 1998; Wenger-Trayner et al., 2015). As we concentrate on the landscape of issues surrounding the practice of living labs and their possible solutions, a CoP is a well-suited approach. In the CoP, the various participants gathered to exchange informally, co-create knowledge, and share challenges and best practices for peer-to-peer learning.

The CoP around living labs was formed initially within the International Sustainable Campus Network (2017) and extended after the Amsterdam Institute for Advanced Metropolitan Solutions (AMS) intensified activities around urban living labs and brought together international living lab practitioners at yearly summits (from 2019). As a result of the documented sessions, the CoP published tools, guidelines, and playbooks. Core CoP participants were from Concordia University, Delft University of Technology, Swedish University of Agricultural Sciences, Utrecht University, Vienna University of Technology, Forum Virium, and the AMS. In monthly documented sessions over two and a half years (from September 2020 to February 2023), various critical aspects of urban and campus living labs were highlighted, elaborated upon, and analyzed, e.g., activities within living labs, success indicators, monitoring, ethics, impacts, process steps, knowledge management, business models and funding, and issues around the Campus as a Living Lab. Participants provided many practical case examples to support these topics throughout the sessions.

Under the umbrella of the CoP, a specialized sub-group was formed, focusing on the topic of living labs in HEI contexts, particularly the Campus as a Living Lab. That sub-group comprised the author team. In the sub-group, the relevant CoP session documentations were further elaborated, synthesized on a higher level, and complemented by reviewing relevant literature to derive and further develop concepts, approaches, and methodologies. Further, three international cases were used as input: The Delft University of Technology (TU Delft) in the Netherlands, the Swedish University of Agricultural Sciences (SLU) in Sweden, and the Concordia University in Canada. The authors are affiliated with those universities. As all universities are located in different settings and have different campus configurations, they serve as diverse case examples: TU Delft's campus is connected to the city of Delft yet situated in a distinct area, whereas Concordia University is more integrated into the city of Montreal and spans across two campus areas. SLU's three campuses are located in different urban regions across Sweden and span from urban to peri-urban and rural landscape characters.

The various theoretical and practical working results were iteratively tested and validated in international settings comprising the CoP, various conferences, and dedicated workshops (from October 2022 to October 2023). This led to adapting, fine-tuning, and streamlining the presented work through peer-to-peer evaluation (academic and non-academic) and iterative feedback loops. Heuristic models arise through observation and experimentation, describing processes leading to choices rather than solely concentrating on end results (Mousavi & Gigerenzer, 2017). With this in mind, our approach suits the aim of offering support for HEIs by developing such a heuristic model. In the course of this work, comments on the results decreased while recognition increased. Thus, this chapter builds upon a triangulation of different knowledge sources and validation approaches (shown in Figure 5-2) that mutually influenced and fed each other to arrive at a heuristic to support HEIs in their quest to utilize the Campus as a Living Lab.

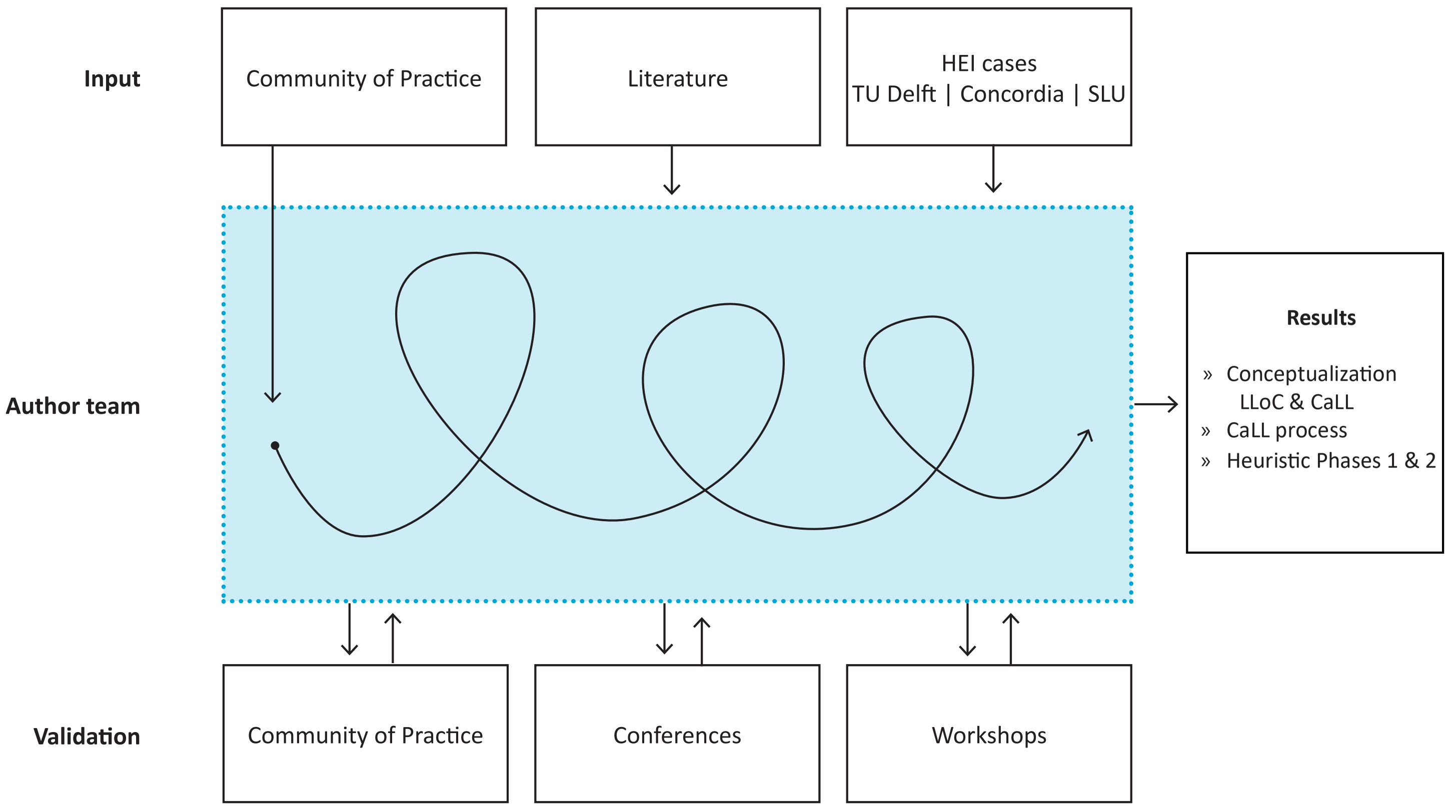

Figure 5-2: Methodology of the development of the Campus as a Living Lab conceptualization, process, and heuristic

5.4 RESULTS

5.4.1 Establishing the concepts of Living Labs on Campus and Campus as a Living Lab

Living labs provide an opportunity for HEIs to collaborate with community stakeholders to address real-world challenges. They may either participate in (urban) living lab partnerships in their region or host them on campus. Instead of building separate laboratories to conduct experiments under controlled conditions, HEIs now involve their campuses, staff, and students in experiments (Nyborg et al., 2024). Although several living labs on HEI campuses have provided insights into their potential for sustainable development (see, e.g., J. Evans et al., 2015; König, 2013; Leal Filho et al., 2017; Leal Filho et al., 2020), they were primarily stand-alone solutions that were not connected. A new, more impactful approach is needed to create effective connections, generate synergies between experiments, and provide a solid database for knowledge sharing and further innovative investigations. As a result, rather than containing laboratories, HEIs themselves serve as laboratories engaged in co-creative collaborative processes.

This implies a difference between the notions of Living Labs on Campus (LLoC) and the Campus as a Living Lab (CaLL). The whole campus could be proclaimed a living lab where networks, coordination, and collaboration are inherently established in a transdisciplinary way. We call this ‘Campus as a Living Lab.’ In contrast, the approach with single living labs, which do not exchange knowledge and data nor follow an orchestrated approach, is seen as “Living Labs on Campus.” While LLoC can establish a low threshold to get started and serve as proven reference examples, the CaLL can create additional value on various avenues. The unique characteristics of the CaLL approach are the continuous creation of synergies between projects, experiments, and testbeds to achieve joint learning, knowledge-, and data exchange, allowing informed decision-making and efficient use of resources. Moreover, CaLL can further data democratization, a topic gaining increasing attention. It aims to remove data gatekeepers and bottlenecks and empower non-specialist groups to access and use data, allowing them to participate in planning and policy discussions (Sawicki & Craig, 1996). This could accelerate sustainability transformation processes by enabling informed decision-making at all levels. That said, the CaLL leads to various organizational and cultural consequences and could function as a platform. The campus would become a defined scientific and practical test site where innovation and learning come first. This would contribute to transdisciplinary capacity building and cross-fertilization through learning across projects, experiments, and organizational entities.

To summarize, we identify the following characteristics as key elements of Campus as a Living Lab: The approach is framed around a shared vision and purpose in the HEI and functions as a fertile ground and platform for diverse experiments, labs, testbeds, and projects, like a large-scale petri-dish. The campus is used as an arena for co-production, co-creation, and transdisciplinary capacity building. CaLL utilizes open innovation processes to accelerate the implementation of experiments and pilot projects while leveraging all relevant (local) knowledge sources, thereby fostering and stimulating engagement and empowerment. Thus, the campus becomes a valuable forum for critically discussing values and ethical issues, growing trust, and providing a testbed for technological and social innovation. A science-based approach accompanied by practice-based research enables replication, knowledge transfer, knowledge mobilization, data democratization, and solution-finding for tailored (local) solutions by encouraging experiential learning processes.

The different approaches that support the sustainability transformation using campus resources are highlighted in Figure 5-3. They range from small campus experiments to strategically anchored initiatives concerning the campus infrastructure, LLoC, and CaLL. Regarding the aim of this paper, we further focus on LLoC and CaLL. While LLoC could be an option of lesser resistance and a lower threshold to get started due to lower coordination needs, implementing CaLL means moving forward in the direction of holistically integrating transdisciplinary research into organizational structures (Martek et al., 2022) and performing required change management processes. This means that a CaLL implementation provides not only the chance to mine for synergies between initiatives but also affects the HEI's operation. In light of this, CaLL is presented as having higher coordination needs. Implementing the CaLL approach can be challenging as HEIs are power-structure-driven organizations and rather slow to change (Leal Filho et al., 2019; Lozano et al., 2013). However, the methodology allows for transdisciplinary collaboration, a precondition for co-creating scalable and replicable innovative and disruptive solutions to complex challenges.

An initial SWOT analysis can be a starting point for an informed decision on which approach to use. Table 5-1 presents the author's exemplary SWOT analysis for LLoC and CaLL, drawing on their experiences in the three cases presented. Of course, every HEI needs to analyze its specific contexts and considerations individually to make an informed approach choice. In conclusion of our analysis, we can say that LLoC can be driven bottom-up by engaged individuals, with less formal structures and thus needs less coordination effort. Even though the LLoC approach might be easier to get started with and has the potential to deliver first results that might engage others to follow, it might be hindered by the lack of strategic backing, resources, and processes, forcing each living lab to "reinvent the wheel," with few options (other than individual contacts) for cross-case learning. CaLL, on the other hand, creates opportunities to overcome these shortcomings by developing strategically embedded structures backed by top management within the HEI organization. There is an elevated need for coordination. However, effective coordination may lead to providing guiding structures, resources, and clear mandates. Particularly, the network might enable cross-fertilization and cross-learning, eventually creating opportunities for designed serendipity. However, there is a risk of creating centralized and formal coordination systems that impair creativity and bottom-up approaches.

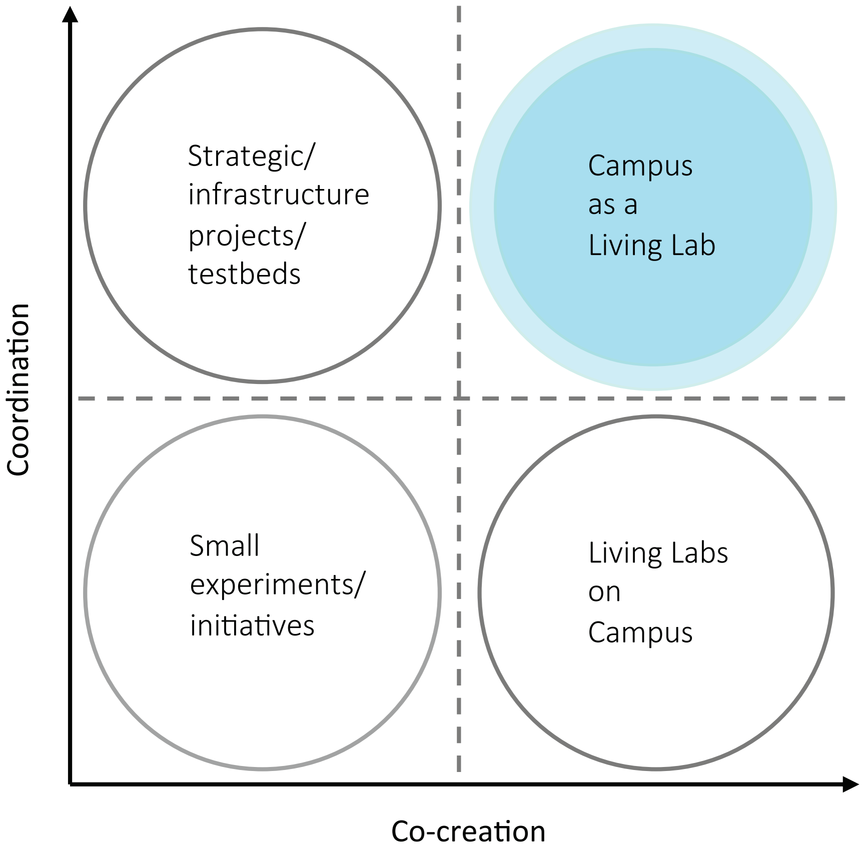

Figure 5-3: Different approaches in utilizing a HEI's campus for the sustainability transformation

Table 5-1: Exemplary SWOT analysis of the Living Labs on Campus (in yellow) and Campus as a Living Lab (in blue) approach; own elaboration

Strengths	Weaknesses
LLoC · A low threshold to get started (does not seem too big; start with one and see how it works >> A good example will lead others to follow) · Showcasing what the university is working on – thematic demonstrations · Relevant societal questions	**LLoC** · Sharing of lessons learned and impact monitoring might stay project-based · Connection between LLs might be weak due to work with individual project management approaches · Potentially unclear insights on actual responsibilities/management · Focus on single LLs may lead to weak network effects/cross-fertilization · Unused potentials of the campus site
CaLL · LL network and cross-LL-learning on campus · Understanding all campus facilities as potential living lab sites (physical sites as well as organization) · Change of perspective on how the campus is used and its role in society · Showcasing how transdisciplinary networks and ecosystems can work on a systemic level	**CaLL** · Coordination on a larger scale, as well as time and human resources, are needed · Funding in general and for coordination positions (several capacities and skill sets needed) · Initiating and maintaining a cultural shift like open research environments and complexities and involving more than the university actors · Complexity, in combination with uncertainty – creates barriers to getting started and challenges to maintain it

Table 5-1: Continued

Strengths	Weaknesses
Opportunities	**Threats**
LLoC · Testing ideas, developing new roles, and relevant/directly applicable outputs · The opportunity of transdisciplinary learning (LL theme) invites transdisciplinary research to take place, develop transdisciplinary capacities · Working on applied societal questions – immediate relevance	**LLoC** · Ad-hoc single-case decision-making (no alignment with the overall vision, campus plans, financing, etc.) · Benefits and learnings are not shared · Variety of (or even contrasting) understandings of what a LL/testbed/ field lab/etc. is · Lack of guidelines and backing by HEI when initiated by individuals
CaLL · Emphasizing HEIs' role and responsibility in society through relevant societal LL themes (and LL networks on campus) · Embedded organizational learning · Visibility/awareness of the HEI externally · Rising international (and national) network opportunities to explore the role of CaLL – peer-to-peer learning / CoP · Capacity building (internally – knowing the HEI's potential; externally – establishing a variety of networks) · Research on LL networks/ecosystems · Central support (funding, expertise, networks) and coordination (administration) - strategic action on the HEI level · CaLL provokes transparency of organizational structures and directions · CaLL can form an identity for the university and be a competitive advantage · Clear mandate through CaLL creates more safety and interest of stakeholders to engage	**CaLL** · Difficulty with coordination/ responsibility may lead to negative perceptions and rejection · Another centralized HEI body · HEI bureaucracy and formality might kill creativity and innovation · Underestimating the management and administration needs · Need for continuous higher management support and clear mandate (high threshold to get started) and engaged bottom-up initiatives

5.4.2 Development phases of the Campus as a Living Lab

Previous research showed that living labs move through different phases, calling for accounting for their distinct circumstances, contexts, and phase-specific needs (e.g., Herth, 2024a; Martek et al., 2022; Save et al., 2021; Steen & van Bueren, 2017). Likewise, a one-size-fits-all-at-any-time approach will not suffice to support and guide the approaches outlined in Figure 5-3, particularly in the context of CaLL. Therefore, we propose a dynamic model that facilitates reflexive processes during the progressive development process of the CaLL. The model comprises four overarching development phases – preparation, start, operation and proliferation, and diffusion (refer to Figure 5-4). These phases denote levels of development or maturation rather than strictly delineated stages and are characterized by iterative co-creation, evaluation loops, and feedback-and-forward mechanisms to drive maturation. Evaluation processes occur in all phases to review and adapt the format, framework conditions, and mission statement. The dashed arrows in Figure 5-4 indicate these processes. Contrary to the processes of single living lab initiatives or campus projects, once successfully established (phases one and two), the CaLL operates continuously, creating the breeding ground and cross-fertilizing conditions (petri dish) for the proliferation of initiatives on campus. Subsequently, both the diffusion of single initiatives and the CaLL setup itself may occur through replication or scaling to other campuses or cities. At the same time, the CaLL keeps operating on the home campus. We will discuss the development phases in more detail in the following.

During the first phase, the focus lies on screening and establishing preconditions for a CaLL, such as assessing the availability of core competencies in the HEI, getting a clear picture of internal and external vital actors, discussing values, framing a problem description, and outline potential impacts of the chosen approach. Subsequently, the second phase involves the practical start of the Campus as a Living Lab. Many practical matters need to be addressed to tailor and embed the CaLL within the organization, e.g., the governance structure, the assignment of roles and mandates, responsibilities, resources, KPIs, monitoring loops, timelines, and a financial framework. In the third phase, the CaLL is operating, fostering co-creation and value creation through various living labs, experiments, projects, and testbeds. Creating synergies and aligning with agreements set in previous phases or adapting them based on changes in circumstances requires continuous co-creation, coordination, reflection, and evaluation processes. The campus serves as a proliferation ground for sustainable innovation initiatives, fostering their impact within the own organization and beyond. Finally, in the fourth phase, tangible and intangible knowledge and outcomes of single initiatives, clusters, or CaLL structures and processes are further refined for communication, scaling, transfer, embedding, and adaptation to different settings, potentially influencing policymaking and broader change processes.

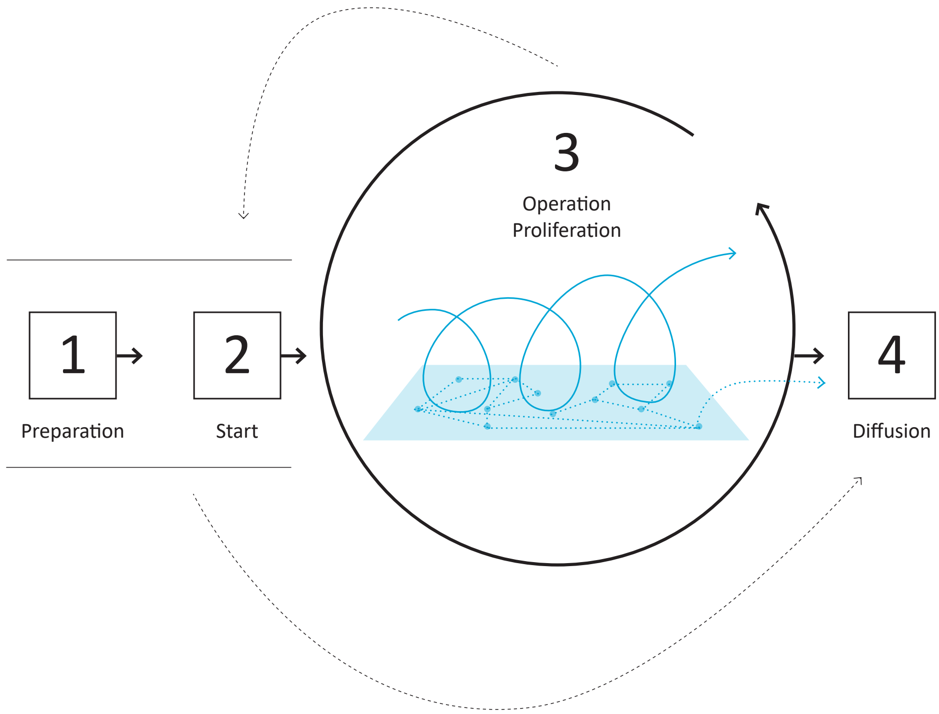

Figure 5-4: Process and phase model of a Campus as a Living Lab

5.4.3 Actionable heuristic to set up the Campus as a Living Lab

As the first step towards establishing a CaLL, we focus and elaborate on the initial two phases of setting the stage and getting started. To that end, we introduce a heuristic in the form of canvases for those two phases. The fields of both canvases were inspired and partially derived from CoP sessions, as well as a literature review of (campus) living labs (e.g., Du Preez et al., 2022; Martek et al., 2022; Save et al., 2021; Herth, 2024b; Steen & van Bueren, 2017; Verhoef & Bossert, 2019). The canvas content doesn't display strict orders of to-do items, nor does it provide an exhaustive list of them. Instead, the canvases must be understood as a compilation of the essential components that each HEI must consider and answer individually. Even though the components are arranged in some structure, any component could be a starting point. There is no underlying indication of importance or priority as, at this point, all components are considered equal. They are designed to trigger and support iterative and creative thinking by developing and reflecting on one's own organization and structure. Reflecting the iterative and flexible nature of a CaLL, some canvas components overlap even across phases. The canvases and their exploratory, reflective, and progressive components thus contribute to the dynamic journey of a CaLL and allow a joint learning and development process.

5.4.3.1 Phase 1: Preparation

As described earlier, the necessary conditions are established during this phase, which can be viewed as the incubation phase. The following canvas (Figure 5-5) provides practical oversight and reference during this first phase. It presents points to discuss, reflect on, and consider when embarking on a CaLL approach. It involves co-creation events and cycles to establish a commonly supported and shared understanding of what is envisioned with the CaLL and why. It also comprises, e.g., the analysis of available competencies, developing a shared understanding of a transdisciplinary way of working and the nature of a CaLL, scouting for resources and capabilities, identifying key actors (internal and external), and assessing the value of the chosen approach and its potential impact.

A brief explanation of the different components mentioned in the Phase 1 canvas is presented here. An overview with exemplary guiding questions and tasks for each canvas module is presented in Appendix I.

Analyze the existing setting (see Figure 5-3) of performing living labs/ projects/testbeds/experiments

This field is intended to elaborate and reflect on the status quo of ongoing activities on the campus that could be onboarded to create buy-in and use existing momentum and resources. The aim is to get a clear picture of what is available already and what needs to be created. Analyze if a CaLL is feasible, viable, and desirable.

Co-create a topic, a shared vision, and definitions for keywords to prepare a common ground and a communication strategy

To start the process, the core group driving the development of the Campus as a Living Lab needs to agree on wording and definitions. It needs to ensure that all stakeholders have the same understanding to prevent misunderstandings right from the beginning.

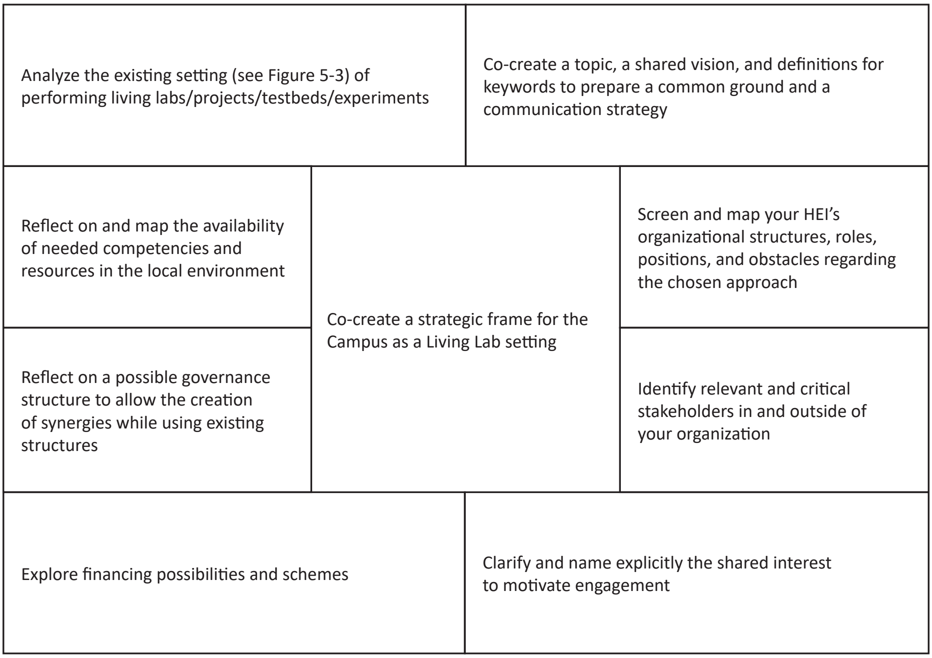

Figure 5-5: Canvas for Phase 1 of the Campus as a Living Lab approach; components are considered equal, and any can be a starting point

Reflect on and map the availability of needed competencies and resources in the local environment

This module aims to create an overview of existing and required core competencies within campus premises. Also, which competencies does the accessible innovation ecosystem provide (external stakeholders)? This mapping exercise will help to identify who needs to be involved in the process from the beginning.

Reflect on a possible governance structure to allow the creation of synergies while using existing structures

For the CaLL approach, the governance structure and key stakeholders' buy-in are relevant. To put the approach on a stable foundation, it is vital to start early to frame possible governance approaches to allow an informed and promising course of action.

Screen and map your HEI's organizational structures, roles, positions, and obstacles regarding the chosen approach
Contrary to the working modes of living labs, HEIs are highly structured and formalized organizations. To streamline a CaLL approach and enlarge the support base, it is essential to integrate CaLL fundamentally into the existing structures and avoid creating parallel ones.

Identify relevant and critical stakeholders in and outside of your organization
A CaLL approach asks for specific (eventually new) internal and external competencies and resources tailored to the HEI's local environment. Therefore, it is important to know if the intended activities align with those of local innovation drivers, e.g., from the private sector, the municipality or regional government, citizen groups, or even other HEIs, or if it is required to frame them in such a way that they differ from or complement the others' activities.

Co-create a strategic frame for the Campus as a Living Lab setting
Start reflecting and developing the strategic frame. It should be co-created to establish a robust foundation that embraces diverse stakeholder groups and focuses on impact generation and value creation in the local environment.

Explore financing possibilities and schemes
Financing schemes and opportunities need to be explored from the beginning so that the CaLL can start with adequate financial resources. Additionally, an overview of diverse resources that can be leveraged over time should be created. This is so that the CaLL does not fail due to financial hurdles at a later stage.

Clarify and name explicitly the shared interest to motivate engagement
The key to creating momentum is understanding the drivers and, specifically, the different stakeholder groups' shared interests. In addition, it is important to understand what topics and outcomes can keep these groups engaged.

5.4.3.2 Phase 2: Getting started

After clarifying the preconditions and taking some important strategic decisions during the previous phase, the second phase focuses on well-directed actions to get the CaLL started and deeply anchored in the organization. Several practical issues need to be addressed, e.g., clear mandates, roles, and responsibilities need to be assigned, resources allocated, and goals and timelines established. The following canvas (Figure 5-6) guides the process by presenting the key elements of this phase.

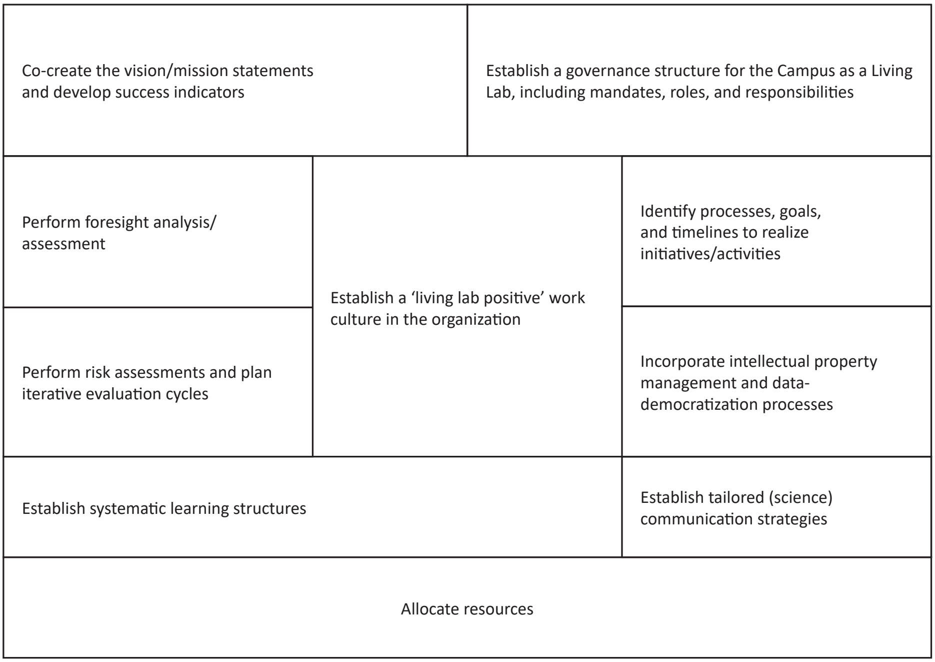

Figure 5-6: Canvas for Phase 2 of the Campus as a Living Lab approach; components are considered equal, and any can be a starting point

A brief explanation of the different components mentioned in the Phase 2 canvas is presented here. The overview with exemplary guiding questions and tasks for each canvas module is presented in Appendix J.

Co-create the vision/mission statements and develop success indicators

Develop and fine-tune the vision/mission statements further and define success indicators for the process by using all relevant outcomes of Phase 1.

Establish a governance structure for the Campus as a Living Lab, including mandates, roles, and responsibilities

A well-documented governance structure should be developed and implemented to run the living lab setting smoothly and transparently, allow promising innovation and idea management processes, and create synergies and cross-fertilization.

Perform foresight analysis/assessment

Set up the CaLL framework in such a way that it allows agile processes to deal with future predictable and unpredictable developments. Aim to design for serendipity.

Perform risk assessments and plan iterative evaluation cycles
Experimenting and secure and reliable campus operations are not easy to coordinate. Therefore, it is vital to establish and maintain a setting that allows for both while undertaking rigorous risk assessment and iterative evaluation cycles to balance both needs.

Identify processes, goals, and timelines to realize initiatives/activities
To coordinate multiple interlinked initiatives within the CaLL, there is a need to define processes for selection, guidance, synergy generation, data collection, and evaluation.

Incorporate intellectual property management and data-democratization processes
Transparent and clear agreements for eventual IP rights and data management should be made right from the start to prevent major judicial interventions.

Establish a "living lab positive" work culture in the organization
Traditional work structures in HEIs are hierarchical and do not match the agile needs of living labs. To create a 'living lab positive' culture that emphasizes transdisciplinary co-creation and collaboration, it is necessary to start implementing change processes to allow for that kind of innovation and value creation.

Establish systematic learning structures
Once initiatives/activities are running, learning is often an omitted point, even though it holds much value and is considered a key element. Learning is one of the vital parts of living labs, so those structures need to be established from the beginning. Experiential learning is of high value and can have significant impacts on bridging silos and enhancing cross-fertilization.

Establish tailored (science) communication strategies
In the CaLL process, tailored communication about ongoing activities and initiatives is crucial. Different stakeholder groups require tailored information provision to stay informed and engaged. In addition to being listened to, information is a significant driver. Further, the HEI also accomplishes its third mission.

Allocate resources
In addition to senior leadership commitment, it is crucial to allocate adequate resources (financial and human) to enable the smooth operation of impactful activities. This is critical to getting started and ensuring the continuity of the CaLL in the long term.

5.5 CONCLUDING REFLECTIONS

This chapter aimed to support HEIs through a heuristic model in their targeted engagement in a Campus as a Living Lab approach for sustainable innovations with real-world impact. By applying a co-creative, transdisciplinary, and iterative research approach, we adopted key elements of living labs in our way of working. We drew on a pool of knowledge from an international Community of Practice for living labs, interactive conferences, workshop sessions, our experiences in three HEI cases, and the current body of literature to conceptualize both the notions of LLoC and CaLL. While the current landscape of HEIs' approaches reveals a prevalence of the LLoC approach (as defined in this chapter), this study marks a significant evolution from the LLoC model to introducing and establishing the concept of CaLL. Doing so lays the groundwork for a shift in how HEIs approach living lab initiatives. Herein, the four-phase CaLL process model provides HEIs with a structured and self-reflective framework to guide their efforts in implementing and navigating that endeavor. Furthermore, introducing the heuristic model for the initial two phases of a CaLL's establishment addresses a critical gap in existing literature and practice. It equips HEIs with tangible and actionable guidelines, responding to the need for a systematic approach when implementing CaLL.

While this study contributes valuable insights into integrating the CaLL within HEIs, it is essential to acknowledge certain limitations. The study engages in only two of the four identified CaLL phases, leaving potential gaps in understanding the complete and iterative process. Hence, there is a clear opportunity to add to the comprehensive understanding of the entire CaLL process by developing phases three and four. In the elaboration of phases one and two, the canvas modules call for quite fundamental organizational change and transformation processes, which naturally leads to further research questions. The predominant focus on conceptual work leaves practical application untested, yet planned case studies are on the horizon. Future research could explore use- and reference cases to gain insights into the heuristic's practical utility and effectiveness in diverse HEI settings. This would enrich the conceptual foundations established in this study and contribute to further developing applicable guidelines.

The initial CoP, as described in the method section, is further developing and growing at the moment of writing. Presentations and discussions around our frameworks at the International Sustainable Campus Network (ISCN) conference in 2023 resulted in significant interest from other HEIs and the network organizers, as they are concerned with similar questions and development processes. The remarkable interest from 45 HEIs across 20 countries in joining a CoP around the Campus as a Living Lab at the ISCN level, based on the conceptual foundations outlined in this chapter, underscores the high relevance of our work. This is further underlined by the questions and issues that motivated the HEIs to participate. We have begun addressing topics such as different approaches to campus living labs, institutional and structural set-up requirements, key elements necessary to establish an effective and efficient CaLL, best practices, and lessons learned in this study. As a next step, the participating HEIs could provide extensive international case studies applying the phase model and the heuristic. Equally, they could allow for a meta-study, extending the perspective beyond single CaLL settings in specific local contexts. Furthermore, as our study is grounded in a European/North American perspective, this CoP could also integrate perspectives from the Global South.

In conclusion, the Campus as a Living Lab presents a promising change towards a more dynamic and comprehensive paradigm. It can be a significant advancement and a more impactful approach by functioning as a catalyst for innovation and change within HEIs and their surrounding (innovation) ecosystem. The study's results facilitate cross-fertilization and unlock currently unused potential within HEIs, fostering a collaborative, reflexive, progressive, and innovative approach to sustainable development. To sum up, this research conceptualizes CaLL and offers practical construction elements for HEIs seeking to embark on this transformative journey. As institutions continue to refine and adapt these concepts and deploy the heuristic in their local organizational contexts, the journey toward a Campus as a Living Lab will undoubtedly progress, marking an exciting and transformative development for HEIs worldwide.

Chapter 6

Conclusions

6.1 OVERVIEW OF THE DISSERTATION

Mitigating climate change requires all sectors to engage in transitions towards sustainability, including Higher Education Institutions. They even play a dual role as they generate and disseminate knowledge and have to undergo their own sustainability transitions. On-campus living labs can be a convener for HEIs to engage in both these roles. The research in this thesis addressed the challenges faced by campus living lab participants from an intra-organizational perspective, identified enabling factors for campus living labs across different development phases, explored the concept of the Campus as a Living Lab, and pinpointed impactful focus areas for campus innovations by analyzing TU Delft's carbon footprint and emission hotspots. Each chapter was guided by one of the following questions, aiming **to understand how campus living labs can contribute to the transition toward climate neutrality**:

- What challenges are encountered by participants in on-campus living labs, particularly from the intra-organizational HEI perspective?
- Which factors enable the well-functioning of on-campus living labs, and how do they vary in significance throughout living labs' different phases of development?
- How can the "Campus as a Living Lab" be conceptualized, operationalized, and practically implemented?
- What is the complete carbon footprint in the case of the Delft University of Technology, including both direct and indirect emissions?

Instead of repeating the content of this dissertation in detail here, I want to discuss and reflect on the broader context. Throughout the different chapters, the results kept playing out on two different levels. Firstly, on the level of living labs themselves, and, secondly, the organizational and contextual level of the HEIs. On the one hand, this dual focus was intentional from the start, as shown in Figure 1-2 in the Introduction, which conceptualized the chapters on these two levels. On the other hand, the results of Chapters 3 and 4, which addressed the inner workings of campus living labs, also contemplated their organizational context. This dual perspective underscores the complexity of "simply" facilitating living labs on campus. To address both levels, the main findings, conclusions, and contributions are presented accordingly, expanding from campus living labs (6.2.1) to HEIs (6.2.2). Figure 6-1 illustrates these two perspectives and the interaction between the levels.

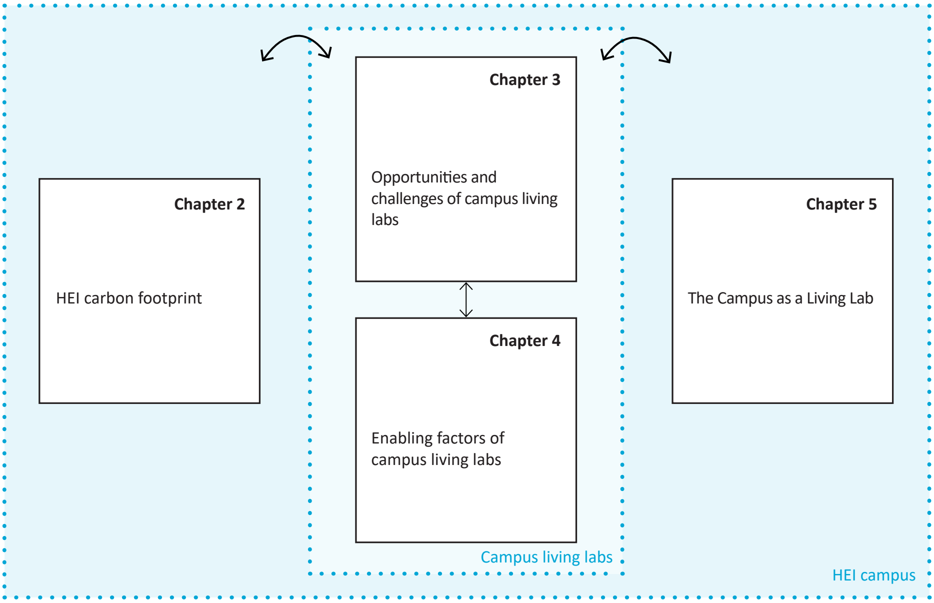

Figure 6-1: Overview of the chapters indicating the dual perspective of campus living labs and the HEI context

6.2 MAIN CONCLUSIONS AND CONTRIBUTIONS

6.2.1 Campus Living Labs

6.2.1.1 Main findings – How campus living labs work on the insight

On-campus living labs are still quite unique but hold significant potential as study cases. However, researching them is challenging due to their complex, heterogeneous nature influenced by numerous factors. Previous studies indicate that much remains unclear about their way of operation, effectiveness, and impacts, as research in HEI contexts is still nascent. Addressing that gap, Chapters 3 to 5 took an explorative stance, contributing to a better understanding of campus living labs' inner workings and conceptualizations. Creating the local conditions for campus living labs to flourish is challenging, as discussed in Chapters 3 and 4. **Chapter 3** explored the opportunities and challenges of campus living labs concerned with the energy transition. The results showed that they face several living lab internal and external challenges. Internal challenges are connected to their own complex inner workings, including the need for a clear set-up, front-end user integration, well-coordinated administration, and effective governance to facilitate stakeholder collaboration. Further, they face living lab external challenges that are connected to their environment, like embedding living labs into the organizational HEI structures and coordination and resource allocation on the HEI level. Another critical challenge for campus living labs is bridging intra-organizational tensions between academic and operational processes.

Even though awareness about the challenges encountered on campus might lead to better facilitation in general, it does not automatically translate into the successful enabling of their operation. Therefore, **Chapter 4** investigated enabling factors to bridge that gap and better understand how to effectively facilitate campus living labs in their specific contexts. While there is no one-size-fits-all solution for setting up and operating campus living labs, several enabling factors can facilitate such initiatives within diverse HEI contexts. Of the sixteen factors presented, the five most pertinent ones represent the core of living labs themselves: early engagement of relevant stakeholders and the wider network, including experts and users, while ensuring equitable participation and avoiding dominance is crucial. Internally, HEIs should establish coordination and governance structures guided by a centralized coordination point and a clear innovation vision. Strategic coordination should involve tailored approaches, defined processes, continuous communication, and capacity building, all while balancing top-down and bottom-up initiatives and maintaining a flexible operational framework. Supporting a transdisciplinary work culture is essential, emphasizing flexibility, informality, and proactive collaboration to encourage experimentation and innovation. Effective co-creation around shared goals and user engagement is crucial, requiring trust, respect, and community among stakeholders.

The Chapter also emphasized the importance of considering living labs' developmental stages and their specific facilitation requirements by exploring the factors' salience throughout these phases: preparation, start, value creation, and transfer and scaling. With a developed mapping exercise, that can itself serve as a discussion tool in living labs, experts were invited to indicate relevant factors in those development phases. The results suggest that factors such as the stakeholder network, continuous learning, and a shared understanding are vital throughout all phases. Other factors are deemed more influential in specific phases. The initiation phase relies on adequate leadership, effective coordination, active stakeholder engagement, a conducive work culture, and sufficient funding. Shared understanding, efficient internal management, robust stakeholder collaboration, methodological appropriateness, and continuous and thorough evaluation enable the more operational phases. Lastly, the dissemination phase centers around the appropriate transfer, embedding, and scaling of solutions, comprehensive evaluation, processing, and sharing of learnings, and bridging stakeholders and contexts.

The findings of both Chapters 3 and 4 suggest that coordination and organizational embeddedness are critical points. As such, there is a growing demand for concepts and tools to support HEIs in implementing campus living labs and establishing the campus as a living lab. In **Chapter 5,** the previous findings are translated into two distinct approaches. The chapter introduces the concept of "Campus as a Living Lab," surpassing the scope of individual initiatives ("Living Labs on Campus"). Living Labs on Campus and the Campus as a Living Lab differ primarily in scope and integration. Living Labs on Campus refers to individual stand-alone labs on campus that operate independently with limited coordinated knowledge exchange or data sharing. Yet, they provide a straightforward starting point for on-campus experimentation and innovation for many HEIs. In contrast, the Campus as a Living Lab adopts a more integrated approach, where the entire campus and its organization function as a living lab. Here, the campus and the HEI organization are seen as a fertile ground for experimentation and innovation with a platform character, in a metaphorical sense, comparable to a "petri dish." This approach fosters synergies between campus initiatives, cross-pollination, and transdisciplinary collaboration for effective knowledge and data exchange, facilitating informed decision-making and resource efficiency. The Campus as a Living Lab leverages all relevant (local) knowledge sources to empower broader participation in planning and policy discussions and accelerates sustainable transformation by embedding and working around a shared vision within the HEI. Although requiring more coordination, the Campus as a Living Lab approach is expected to have a greater impact on accelerating sustainability transitions and transformation processes due to its characteristics described above. Consequently, the Campus as a Living Lab is a comprehensive platform for innovation and learning, driving significant contributions to sustainability and capacity building. Whereas the current landscape shows a prevalence of the Living Labs on Campus approach, this chapter also introduces a four-phase process model and heuristic guidelines for the initial Campus as a Living Lab phases, providing HEIs with a structured framework and actionable guidelines to navigate this transition. The phase model and the developed heuristic to support HEIs in launching the Campus as a Living Lab are further presented in section 6.2.2.1, which focuses on the HEI context.

6.2.1.2 What enables campus living labs is also challenging and the other way around – Areas of special attention

Triangulating the findings from Chapters 3 and 4 reveals that the challenges and enabling factors of campus living labs are complex and interconnected. The overlaps between challenges and enablers reflect the intricate nature of campus living labs, consistent with recent studies in other contexts (Berberi et al., 2023). Understanding these mutual influences can enhance the facilitation of campus living labs by allowing practitioners to identify suitable enablers for specific challenges. These findings can help living lab practitioners and HEIs prioritize enablers for identified challenges. While this preliminary discussion highlights initial patterns, further research is needed to investigate these connections scientifically.

The combination of challenges and enabling factors can be considered from two perspectives, both aiming to find matches between them. From the perspective of challenges, campus living labs are facilitated by minimizing encountered hindrances. A challenge that lacks corresponding enabling factors might need special attention, as no enabler might mitigate it. Conversely, from the perspective of enabling factors, living labs are facilitated by their tailored application; ideally, an enabling factor might be applied to address multiple challenges. Thus, the overlap between challenges and enablers is indicative in both perspectives.

The preliminary mapping shows that each enabling factor can potentially mitigate several challenges. This is promising for facilitating campus living labs, as there are no challenges that cannot be addressed by the enabling factors identified in Chapter 4. In that chapter, the top five mentioned enabling factors were established. Here, the question arises of how far the challenges identified in Chapter 3 can be tackled with these five factors. The preliminary mapping indicates that all of the mentioned challenges can be addressed by focusing on these five enabling factors. This reconfirms the relevance of these five and suggests they can serve as an effective starting point in facilitating the well-functioning of campus living labs.

The challenges in Chapter 3 were categorized as internal living lab challenges and challenges related to their local context. The top five enabling factors address both levels. For instance, applying fitting methods and tools targets the living lab level, while stakeholder involvement and co-creation processes are relevant at both levels. Creating a conducive work culture and supporting coordination address the organizational HEI level. Here, the rigidity of university administration was perceived as a challenge for campus living labs. Therefore, a crucial enabler is a more flexible, agile, and open work culture that fosters transdisciplinary collaboration and embraces the implementation of innovations emerging from living labs.

This preliminary analysis suggests that the top five enabling factors identified can effectively address all challenges categorized in Chapter 3, emphasizing their relevance as a foundational approach. However, further rigorous research is needed to scientifically investigate these connections and validate their impact on enhancing the functionality and success of campus living labs.

6.2.1.3 Contributions and practical recommendations

By investigating the HEI-internal perspective on challenges for on-campus living labs, Chapter 3 provides a solid foundation for addressing these issues before engaging with external stakeholders. This unique perspective on internal and external challenges within the HEI context offers a more accurate view for other HEIs compared to studies from other contexts. By extracting enabling factors of campus living labs across the literature, Chapter 4 extends beyond single cases to provide a broader perspective for HEIs facilitating living labs. The study synthesizes a set of enabling factors, showing trends in their importance during various development phases, allowing for better-tailored applications. Additionally, Chapter 5 highlights the differences between approaches using the campus for innovations by conceptualizing Living Labs on Campus and the Campus as a Living Lab for the first time.

Understanding these conceptual approaches, inner workings, and facilitation needs throughout living labs' development phases advances the knowledge of living labs in an HEI context. This leads to better practical facilitation and well-functioning initiatives, offering tailored guidance for internal stakeholders while stressing the need to adapt findings to local contexts. The chapters contribute to establishing a shared understanding of living lab approaches in both the scientific literature and within HEIs. The combined understanding of challenges and enablers equips living lab practitioners and HEIs to facilitate these initiatives effectively by highlighting high-priority focus areas previously unknown. Consequently, campus living labs can be better supported in reaching their goals and co-creating sustainable innovations. Thus, the studies in this thesis significantly contribute to the living lab and innovation management literature by enhancing the theoretical understanding and practical implementation of living labs, providing valuable insights for future research and development.

The main findings regarding campus living labs prompt several recommendations for practitioners:

- **Engage relevant stakeholders from the outset**
  Engage all relevant stakeholders from the outset, particularly in the initial stages of establishing on-campus living labs. Address key questions together, such as clarifying motivations for participation and aligning on expectations. Establish a shared understanding and vision for the living lab, defining its purpose, goals, and anticipated impacts beyond project completion. To facilitate that process, use the mapping tool presented in Chapter 4, which ensures the integration of enablers and might trigger discussions around some challenges.
- **Recognize the unique nature of living labs**
  Recognize that campus living labs differ significantly from typical campus projects and require unique facilitation. Ensure all stakeholders, including those indirectly involved through organizational structures, understand the unconventional nature of living labs. Clearly articulate living labs' need for more "room to maneuver" regarding resource allocation, timelines, stakeholder coordination, and outcomes. Embrace and accommodate living labs' inherent uncertainty and openness within operational frameworks, initiative proposals, planning processes, evaluation and learning cycles, and facilitation strategies.
- **Embrace possible friction**
  The diverse working methods of living labs can cause friction with established processes. Recognize and embrace this friction, as it can be a catalyst for innovation. Create flexible, agile, and collaborative structures, and remain open to change to allow living labs to contribute effectively.

6.2.2 Higher Education Institutions

6.2.2.1 Main findings – What campus living labs need from the outside

Even though in the HEI environment, it is a common understanding that the energy transition is needed, it is also evident that making that transition happen is not as easy but a complex task with many stakeholders, interconnections, trade-offs, and changes in thinking and behaving to be considered. However, where to begin? Is it even attractive for HEIs to facilitate living labs on their campuses for the energy transition? As the campus is considered a favorable environment for living labs, why do they struggle in that environment? What can be improved? This section looks at the research findings through the lens of HEIs.

Before HEIs can tackle their emission hotspots, knowing where to direct efforts towards climate neutrality for the greatest possible impact is vital. Therefore, **Chapter 2** analyzed the carbon footprint of the Delft University of Technology, including both direct and indirect emissions, and established a baseline for reduction strategies toward climate neutrality. The study included the often neglected emissions from procurement, which make for the most significant share of the HEI's carbon emissions, highlighting the need for their inclusion in future calculations as well. The highlighted hotspots indicate areas for focused emission reduction efforts. Unsurprisingly, the campus-built environment and construction are the most significant carbon hotspots for the university. The top five emission sources – real estate and construction, natural gas, procured equipment, ICT, and facility services – account for almost 65 % of the carbon footprint, which means that targeted reduction efforts in these areas have a high impact on the total carbon footprint. It also shows that the most significant emission sources directly relate to the university's operation.

These findings lead to two conclusions with campus living labs in mind. First, particularly future campus developments have a direct effect on carbon emissions. Next to relatively straightforward avoidance and reduction strategies, innovation spaces for more complex solutions can be integrated into these developments. Second, about 80 % of the university's emissions were indirect emissions, highlighting the importance of integrating supply chain stakeholders into the university's emission reduction strategies. Together, this makes the campus, its building, infrastructure, and organization an opportune space for living labs, confirming this dissertation's departure point.

Chapter 3 established that campus living labs need to be enabled and well embedded into the HEI organization in order to harness their potential to contribute beyond project realization. However, the current organizational structures of HEIs do not fit the dynamic, flexible, iterative, and transdisciplinary structures of campus living labs. Moreover, for campus living labs to function well, the tensions of the internal operation-science divide have to be bridged. At the same time, campus living labs can be vehicles and boundary objects to bridge that divide.

Even though facilitating the search for sustainable solutions through living labs on campus might be a promising step in the right direction, the mere implementation of some living labs by HEIs seems insufficient. Their task is to create the context for campus living labs to flourish if they want them to contribute to the HEIs' energy transition. An integrated approach, meaning seamless organizational embeddedness into the operation, research, and education structures of HEIs, is needed to fully harness both the potential of the campus living labs and the campus environment. To that end, **Chapter 5** introduced the concept of the "Campus as a Living Lab," as opposed to single "Living Labs on Campus," as an approach to fully utilizing available assets and establishing transdisciplinary connections with relevant third parties, like broader innovation ecosystems, companies, governmental parties, users, and citizens. Hence, the whole campus and the HEI organization are experimentation and innovation environments for sustainable solutions. Implementing the Campus as a Living Lab provides not only the chance to mine for synergies between initiatives and stakeholders but also affects the HEI's operation. The campus is then used as an arena for co-production, co-creation, knowledge exchange, joint learning, and transdisciplinary capacity building. In that light, however, the Campus as a Living Lab has higher coordination needs than other approaches using the campus, including knowledge exchange and organizational integration beyond single initiatives.

Chapter 5 further guides HEIs in their search for how to launch and establish the Campus as a Living Lab. It outlines the Campus as a Living Lab process stages—preparation, start, operation and proliferation, and dissemination—and provides a context-adaptable tool in the form of canvases for the preparation and start phases to facilitate the launch. Contrary to Living Lab on Campus initiatives and campus projects, the presented phases lead to the continuous operation of the Campus as a Living Lab once established. The ongoing operation allows for a breeding ground for new initiatives and the diffusion of single initiatives and the Campus as a Living Lab setup itself (e.g., governance structures) while maintaining operations on the home campus. The canvases to support the launch of the Campus as a Living Lab entail progressive and reflective tasks and questions, including

Chapters 3 and 4 findings. During the preparation phase, the focus is screening and establishing preconditions for a Campus as a Living Lab. The canvas involves several key elements: analyzing the current landscape of living labs, innovation projects, testbeds, and experiments on campus; co-creating a shared vision and defining key terms to establish common ground and a communication strategy; mapping local competencies and resources; considering governance structures to enhance synergy with existing frameworks; evaluating organizational structures, roles, positions, and potential challenges; identifying critical stakeholders within and outside the organization; developing a strategic framework for the Campus as a Living Lab; exploring funding options; and clearly articulating shared interests to foster engagement. The phase marking the actual start of the Campus as a Living Lab involves addressing practical matters to tailor and embed the Campus as a Living Lab within the organization. Key elements are: co-creating vision and mission statements and developing success indicators; establishing a governance structure for the Campus as a Living Lab, including defining mandates, roles, and responsibilities; performing foresight analysis and risk assessments and planning iterative evaluation cycles; identifying processes, goals, and timelines for initiatives and activities; incorporating intellectual property management and data-democratization processes; establishing a 'living lab positive' work culture as well as systematic learning structures and tailored science communication strategies; and resource allocation. By working with the two canvases and adapting them to their local contexts, HEIs may effectively bring the Campus as a Living Lab into operation.

6.2.2.2 Contributions and practical recommendations

Investigating the carbon footprint of the Delft University of Technology contributed to calculating the often neglected scope 3 emissions from HEIs' procurement activities. The results also represent a transparent reference point for other HEIs and thus contribute to better comparable results, which is often an issue in carbon footprint calculations. Besides reviving a critical discussion around calculation processes, Chapter 2 also points to problems in the calculation methods, calling for research to develop better-suited ones. Overall, the study enables HEIs to focus their emission reduction efforts on high-impact areas to reach the goal of climate neutrality sooner rather than later.

Further, HEIs can use campus living labs for sustainable solutions for energy transitions in these high-impact areas. For HEIs to structurally integrate living labs beyond single initiatives, Chapter 5 contributed to clarifying the concepts of the Campus as a Living Lab as opposed to Living Labs on Campus, encouraging and guiding them in the first approach. The conceptualization enlightens the scientific discussion of living labs in HEI contexts. It may aid in better facilitating them tailored to the chosen approach and local contexts, contributing to leveraging their unique position and accelerating sustainable transition and transformation processes.

Even though many HEIs have already integrated the intention of using their campuses as living labs in their corporate or sustainability strategies, further explanations or definitions of what they mean by that and how they intend to achieve that are mostly lacking. The studies reported in this thesis practically support HEIs in this endeavor and underline the practical relevance of this work.

The main findings regarding HEIs prompt several recommendations:

- **Embed living labs organizationally**
  Embed campus living labs within the organizational structure to fully harness their potential for contributing to the energy transition. Prepare the campus as a fertile ground for living labs by creating flexible and stimulating coordination and support structures for transdisciplinary collaboration, continuous evaluation and learning, and a strong support network based on shared understanding and a shared vision. Use the mapping tool topics (Appendix G) as a discussion guide.
- **Systematically set up the Campus as a Living Lab**
  Systematically set up the Campus as a Living Lab by utilizing existing organizational structures and integrating ongoing initiatives. Use the canvases from Chapter 5 (Figures 5-5 and 5-6) for the preparation and practical starting phases to guide the process into the operational phase. Ensure that the bottom-up enthusiasm is met by transparent coordination and governance structures while allowing room to maneuver for initiatives. Be prepared for significant organizational changes and actively foster an environment where the institution is open, willing, and ready to adapt. Embrace these changes by promoting a culture of innovation, flexibility, and continuous learning, and ensure that all stakeholders are committed to evolving the organization's practices.
- **Learn from other HEIs**
  Engage with other HEIs pursuing similar goals to quickly overcome hurdles and avoid reinventing the wheel, benefiting from shared knowledge and experiences. Communities of Practices can be a valuable learning source for that.

- **Incorporate scope 3 into carbon footprint calculations**
  Last but not least, on the path to achieving a climate neutral campus, start by including scope 3 emissions in continuous carbon footprint calculations to capture all significant emission sources. Use these results to identify high-impact areas for emission reduction and consider leveraging living labs to develop innovative solutions to complex challenges.

6.3 FUTURE RESEARCH AVENUES

Having taken another step in understanding how campus living labs and the Campus as a Living Lab can be facilitated to contribute to a more sustainable future, future research avenues can be identified based on the studies in this thesis. Even though the four presented research avenues also briefly touch upon the limitations of the studies, they are intended to further illuminate relevant paths for advancing scientific, practical, and societal knowledge.

The dark side of campus living labs

The critical debate about living labs takes the side stage in the academic literature. The conceived main mood is an innovation and living lab-positive one, emphasizing the great innovation potential of living labs. This dissertation is no exception to that. However, living labs are not a panacea for anything. In working toward sustainable solutions, their complexities, challenges, inevitable trade-offs, and ethical considerations (e.g., open questions of agency and ownership, participation, inclusion, legitimacy, power, or transparency) require thorough research and a balanced debate. Thus, there is a need for more research that takes a critical stance, like e.g., Pfotenhauer et al. (2022) and Paskaleva and Cooper (2021), who discuss the underlying scaling paradigm and effectiveness of living labs, or Wirth et al. (2019) who reflect on the potential risk of creating real-world experimentation spaces where no one is accountable in the end. The dark sides of living labs, like their potential misuse as buzzwords and cover for a setting where "anything goes," should be further studied. These reflections, however, require atmospheres of openness and trust to be created first. Action research, longitudinal studies, and Communities of Practice could offer promising entry points for researching these issues.

Another point often overlooked, or at least not published, is failed cases (Bauwens et al., 2023; Fanelli, 2010; Turnheim & Sovacool, 2020). There is a lack of reported and discussed unsuccessful living labs in the literature, even though as much as 40 % are reported to fail (Ballon et al., 2018). Yet, an open culture of mistakes is vital for innovation and living labs and should also be engrained in their functioning and learning processes. However, the lack of publications does not align with that proclaimed culture. Sharing the causes and factors of failure is crucial. Without it, valuable learning opportunities are lost, hindering the progress of living labs towards a sustainable future. Conversely, sharing failures, their reasons and solutions can accelerate these processes and outcomes. This raises fundamental questions: What does failing even mean in the context of living labs? How do living labs fail? Based on this work, unsuccessful cases are particularly interesting to investigate to establish which challenges were present,

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which enabling factors were lacking, and in which phase. This could support the challenges and factors found in Chapters 3 and 4 throughout the development phases while further establishing tipping points in the balancing act of campus living lab facilitation. Besides sharing context-dependent best practices, considering cross-case factors for "failure" could deepen the understanding of living labs for their tailored facilitation. However, in an environment where failure has a rather negative connotation, researching it is assumed to be challenging. Nevertheless, creating an environment of trust and room for honest reflection and communication might be time-consuming but not impossible. Communities of Practice or dedicated focus groups could be set up to create protected spaces for reflection and learning on such sensitive topics over time.

Further development of the Campus as a Living Lab

This research avenue includes three points: the further development of the concepts and tools presented in this work, the deployment of the concepts and tools in use cases, and longitudinal studies.

Further development of the approaches, concepts, and tools presented in this work

Chapters 4 and 5 are well-substantiated starting points for further research into the presented concepts and the further development of the tools, such as the mapping and discussion tool or the campus as living lab canvases. The latter have only been developed for the launch phases but not yet for the more mature development stages. This leaves a gap to fill, especially regarding a comprehensive understanding of the transformation process towards a Campus as a Living Lab and its implications for the HEI organization. A better understanding and facilitation of this process also requires developing other kinds of tools to extend the toolbox for the Campus as a Living Lab, focusing on coordination, governance, and learning processes (more on the latter in the following paragraphs). Moreover, referring to Figure 5-3: Different approaches in utilizing a HEI's campus for the sustainability transformation5-3, different approaches lead to different pathways and facilitation requirements. Investigating these pathways could lead to more enlightened transformation roads with appropriate support and guidelines. To that end, different cases in different development stages and intended development approaches could be studied over time.

Validation, adaptation, or redevelopment through use cases

This work, unfortunately, leaves the developed approaches of Chapters 4 and 5 untested in real-life settings. However, their validation and evaluation in use cases are vital to adapting and readjusting them iteratively. Therefore, future research should explore their work in use- and reference cases to gain insights into their practicality and effectiveness across diverse HEI settings. Deploying the Campus as a Living Lab is fundamentally a strategic decision, which means embarking on new pathways and engaging in unconventional processes. Of course, this might have unforeseen consequences and implications, which can be fed back into the conceptualization and the tools for the Campus as a Living Lab. The study of multiple use cases could also appropriately address questions of different Campus as a Living Lab-positive environments and organizations tailored to different contexts. Moreover, they could enlighten the tension between the governance and coordination needs and the empowerment of new bottom-up initiatives that might not fit these structures and frameworks.

Longitudinal studies

Living labs, and particularly the Campus as a Living Lab, are long-term engagements and trajectories, sometimes without explicit start or end. Overseeing and mapping their full development, effectiveness, and impact is difficult. Especially since living labs are dynamic settings and processes, collecting data over a longer period would generate valuable insights. Point-in-time measurements can only present a static picture that does not depict their organic nature. Longitudinal studies not only create value in progress and impact tracking over time but also create more room to investigate the Campus as a Living Lab from different perspectives and consider the already mentioned ethical considerations and failed cases, for example.

Monitoring and impact measurements on campus and beyond

As mentioned in the paragraphs on critical perspectives and longitudinal studies, there is a need for monitoring and impact assessments of campus living labs. What is their actual impact on the sustainability transition (of HEIs and beyond), and how does it manifest? What is, for example, their measurable impact on the carbon footprint towards climate neutrality? These questions, also touch upon the call for developing suitable carbon footprint calculation methods, as we pointed out in Chapter 2. These developments should also address, e.g., avoided emissions as a result of campus living labs. How do we account for the positive impacts these settings might have in other areas of sustainability? On another note, are there ways to compensate for the remaining carbon emissions locally (after avoidance and reduction strategies), maybe even intra-organizationally or with successful living labs? This might even be a question for yet another campus living lab. Monitoring refers not only to actual results and numbers but also to the process of campus living labs and the Campus as a Living Lab itself. Keeping track of their development and process stages might also give insight into under which circumstances unexpected outcomes can arise or, on the other extreme, initiatives fail. With these insights, designing living labs for serendipity might become easier. Equally important is the broader view, which considers the impact of campus living labs beyond the campus boundaries. How are campus living labs translated into cities, and how do they impact local, regional, and even national or global scale? Developing adaptable monitoring and evaluation frameworks that indicate whether, in which ways, and to what extent campus living labs and the Campus as a Living Lab have a local and wider impact is encouraged.

Beyond the local context

This research avenue again consists of three parts. First, intra- and extra-organizational knowledge management and exchange networks. Second, inclusivity and Global South perspectives. Third, campus comparisons and studies beyond the local context.

Knowledge management and exchange networks

In general and from the co-creation process specifically, there is an immense amount of process knowledge and lessons learned from campus living labs. However, knowledge management structures seem lacking in safeguarding, using, sharing, and disseminating that knowledge. As campus living labs are dynamic, emerging, and dissolving structures, storing this knowledge is critical so it does not disappear after it dissolves. This includes all the stakeholders who might go their ways again or individuals who leave organizations. In contrast to other living labs, campus living labs are tied to the HEI facilitating them. Creating a knowledge network and management system should be less complex, as it can be facilitated within the HEI context. Nevertheless, a balance needs to be found between granting space for the organic and dynamic structures of campus living labs and the overarching coordination and management processes, including knowledge management. New avenues should be sought to address and balance these issues.

Extending the view – Inclusivity and Global South perspectives

The type and location of a campus might determine how often and comfortably a campus is frequented by third-party visitors, like companies or citizens. Yet, campuses might also be perceived as exclusive environments (see Chapter 3). Therefore, exploring the inclusivity of campuses and campus living labs and strategies to engage citizens effectively present valuable research opportunities. However, on campus, “users” are not always the citizens. They can also be HEI operation entities or students, for example. Therefore, users might shift from HEI internal stakeholders to, for example, citizens when transferring or scaling campus living labs. This might be a potential pitfall when these considerations are not anticipated from the beginning. Here, monitoring pathways, adaptation processes, and impacts of living labs into their wider environments might prove valuable.

The studies reported in this thesis are mainly based on cases from the Global North and are generally written from a Western perspective. As a result, the findings might be influenced by that worldview. Future research should address this gap by investigating other contexts in the Global South to determine if the results hold or if new insights emerge. How can the concepts be enriched, and in which ways do they need to be adapted? What can we learn from each other's realities in facilitating campus living labs for sustainable transitions? The international Community of Practice around the Campus as a Living Lab, mentioned in Chapter 5, offers a promising opportunity to investigate these questions across diverse cases.

Campus comparisons and studies beyond the local context
Investigating different campus settings and their localities would also be valuable in better facilitating the different needs of campus living labs in these environments. Research can connect to the different campus settings established in the literature and draw on their relationships with cities (den Heijer & Curvelo Magdaniel, 2018). This might also be vital for campus living labs' transfer and scaling processes. For example, which implications do rural campuses have for living labs compared to city-integrated campuses? What does that mean for campus living labs' facilitation and the results of this thesis? How can campus living labs and urban living labs enrich each other? Which campus environment is equipped to address which kind of societal challenges? These are just a couple of questions that would be worthwhile to answer. The same applies to comparing organizational facilitation and embeddedness to create the most suitable environments for flourishing living labs. Therefore, comparing different campus settings and their implications for on-campus living labs is encouraged. Building on campus conceptualizations in the literature, qualitative studies could add implications for the campus living labs and the Campus as a Living Lab (see also previous research avenues).

When the built environment is considered the vertical transfer and scaling axis, other HEIs and their campuses can be considered the horizontal axis. Sharing and using each other's campuses might accelerate sustainable transition processes even further instead of trying to "reinvent the wheel" per organization again. Of course, this would go beyond a single-campus approach. Even though establishing the Campus as a Living Lab is quite a complex undertaking, there is room for further development by including more than one campus. This could happen in two ways. First, HEIs could use each other's campuses for campus living labs, depending on their local context (see paragraph above) or their disciplinary focus. Especially in the Dutch context, where the geographical distance between HEI campuses is sometimes a literal 10-minute train ride, this seems an evident opportunity and a pity to miss. Second, various campuses could be extended by a network of HEIs, where learnings, facilities, space, and living labs are interconnected. This could grow and be managed in a meta-lab approach, where a campus is a part of a more comprehensive network. Different campuses could enrich each other's work by investigating different perspectives of the same societal problem or investigating the impacts on the same topic in different locations, for example. At the moment of writing, establishing one Campus as a Living Lab seems to be complex enough (see Chapter 5). However, Chapter 3 suggested that a vision beyond project realization is essential from the start. With that in mind, the Meta-Campus-as-a-Living-Lab approach should be seen as a vision, anticipating a possible future scenario that needs a more detailed understanding of its implications and facilitation needs. Subsequently, this calls for developing suitable approaches to enable these future pathways.

6.4 FINAL REMARKS

The goal of climate neutrality may seem straightforward, yet the journey to achieve it is more complex. Leveraging HEIs' inherent capacities and resources to cultivate the conditions for campus living labs to flourish can work in symbiotic ways. They can foster an environment conducive to knowledge exchange and innovation through coordinated efforts and participation. Embracing living labs and establishing their campuses as living labs not only underscores HEIs' commitment to change but also enhances their credibility as drivers of sustainable development. By embodying the principles they advocate, HEIs demonstrate their willingness to lead by example, laying a foundation for impactful societal change.

Campus living labs can contribute significantly to climate neutrality by targeting major emission hotspots such as the built environment, energy consumption, and the embodied emissions of procured equipment and ICT-related goods. By diffusing their insights and results, campus living labs can also extend their impact beyond the campus. However, to enable their well-functioning on-campus, it is crucial to eliminate organizational barriers and ensure early and extensive stakeholder integration. Transforming the campus into a living lab can further leverage the high concentration of on-campus experimentation and innovation settings, creating a vibrant, collaborative learning network. This approach could lead to substantial positive ripple effects, greater social and environmental impact in tackling climate change challenges, and an acceleration towards a climate-neutral campus.

Reflecting on the research period, significant changes have taken place at TU Delft. The university's strategic framework has evolved from "Impact for a better society" to "Impact for a sustainable society" (TU Delft, 2024b), highlighting the urgency of and a commitment to sustainability. A sustainability coordinator and team, including faculty, staff, and students, ensures that the university practices what it preaches (TU Delft, 2024c). The QS World University Ranking for Sustainability recently recognized these efforts, placing TU Delft 14th worldwide and naming it "continental Europe's most sustainable university" (QS Quacquarelli Symonds, 2024).

Regarding the focus of this work, TU Delft now includes scope 3 emissions in its annual carbon footprint reports, collaborates with suppliers on sustainable procurement, and has established a governance framework for campus innovation. This framework includes a campus innovation board and team, comprising faculty, staff, and students, to coordinate and co-fund campus innovations like living labs; the first ones are already funded and underway, with more in development (TU Delft Campus, 2024; van Mastrigt & Tax RA RC, 2023). These efforts are substantial strides toward a climate-neutral campus, demonstrating serious commitment to tackling complex sustainability challenges and offering a promising outlook.

In the hope of collective, co-created, dynamic, and iterative further development of the presented research, this dissertation may serve as an actionable base to get started immediately. Even though campus living labs may always be in transition, the time for action is now.

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Appendices

A. THE CARBON FOOTPRINT OF TU DELFT 2018 (SORTED BY EMISSIONS) [CHAPTER 2]

Scope	Carbon footprint category	Description	Activity [x1000 units]
Scope 3	**Real estate and construction**		**58.055,1**
		Additional costs	29,2
		Daily maintenance	153,5
		Electrotechnical works	1.819,5
		Fire safety	305,3
		Guarding buildings	200,0
		Other equipment & inventory	309,1
		Other housing costs	1.553,2
		Project costs university corporate offices	49.695,4
		Relocation costs	267,3
		Rent and leasehold	833,6
		Replacement maintenance	116,7
		Tools	412,7
		Architectural works	2.314,6
		Tools rent	5,9
		Tool maintenance	39,0
Scope 1	**Natural gas TU Delft**		**9.270,8**
		Natural gas consumption	9.270,8
Scope 3	**Equipment**		**28.093,3**
		Electronic/electrotechnical material	1.226,2
		Emergency maintenance	2,4
		Equipment	20.778,6
		Project costs university corporate offices	50,6
		Technical mass items	3.737,3
		Equipment rent	108,8
		Equipment maintenance	2.182,6
		Preventative maintenance contract	6,3
		Units of Account	0,5

Unit	Average Emission Factor [kgCO2eq/unit]	Emissions [tCO2eq]	Note	EF Reference
€	**0,29**	**19.375,3**	Calculated average emission factor	
€	0,46	13,4		b
€	0,20	30,7		c
€	0,52	946,2		b, c
€	0,11	33,6		b
€	0,17	33,0		b, c
€	0,52	160,7		b, c
€	0,12	186,4		c
€	0,33	16.993,1	Emission factor calculated separately	b, c
€	0,12	32,1		c
€	0,17	141,7		b
€	0,29	34,0		b, c
€	0,52	214,6		b, c
€	0,24	543,9		c
€	0,23	1,4		b
€	0,27	10,5		b, c
m3		**17.521,9**		
m3	1,89	17.521,9		a
€	**0,48**	**14.278,9**	Calculated average emission factor	
€	0,52	637,6		b, c
€	0,39	0,9		b, c
€	0,52	10.804,9		b, c
€	0,45	26,3		b, c
€	0,52	1.943,4		b, c
€	0,46	50,1		b
€	0,37	814,8		b, c
€	0,13	0,8		b, c
€	0,11	0,1		c

A

Scope	Carbon footprint category	Description	Activity [x1000 units]
Scope 3	**ICT**		**23.140,5**
		ADSL costs	0,5
		Audio visual resources / optical instruments & equipment	1.895,8
		Computer equipment	5.774,4
		Computer parts	109,9
		Computer supplies	139,4
		Education Service Provision	49,9
		Office machines	14,9
		Other equipment & inventory	24,1
		Project costs faculties	7,3
		Project costs university corporate offices	2.730,0
		Software	679,8
		Subscriptions	3.502,6
		Telephone/fax costs	715,7
		Telephone costs	33,0
		Computer equipment rent	8,7
		Audiovisual equipment rent	134,6
		Office machine maintenance	273,5
		Software maintenance	5.828,7
		Audiovisual equipment maintenance	128,0
		Computer equipment maintenance	66,4
		Office machines rent	1.023,4
Scope 3	**Facility services**		**13.089,0**
		Cleaning buildings	419,4
		Furniture and upholstery	2.412,6
		Furniture maintenance	120,7
		Other equipment & inventory	42,2
		Project costs university corporate offices	9.282,2
		Purchase of faculty cafes	31,6
		Window cleaning	0,2

Unit	Average Emission Factor [kgCO2eq/unit]	Emissions [tCO2eq]	Note	EF Reference
€	**0,38**	**8.353,7**	Calculated average emission factor	
€	0,23	0,1		c
€	0,69	1.308,1		b
€	0,48	2.742,8		b, c
€	0,48	52,2		b, c
€	0,48	66,2		b, c
€	0,16	8,0		c
€	0,56	8,4		b, c
€	0,52	12,5		b, c
€	0,55	4,0	Average emission factor of ICT hardware group	b, c
€	0,46	1.498,3	Emission factor calculated separately	b, c
€	0,16	108,8		c
€	0,28	980,7		b
€	0,27	189,6		b, c
€	0,27	8,7		b, c
€	0,23	2,0		b
€	0,23	31,0		b
€	0,37	102,1		b, c
€	0,16	932,6		c
€	0,37	47,8		b, c
€	0,22	14,3		b, c
€	0,23	235,4		b
€	**0,48**	**8.283,2**	Calculated average emission factor	
€	0,79	329,7		b, c
€	0,59	1.423,4		b, c
€	0,27	32,6		b, c
€	0,52	21,9		b, c
€	0,42	5.702,1		b, c
€	0,39	12,4		b, c
€	0,16	0,0		c

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Scope	Carbon footprint category	Description	Activity [x1000 units]
		Furniture rent	153,6
		Trading goods	99,2
		Removal of environmentally harmful waste	526,9
		Sanitary goods	0,7
Scope 3	**Business flights**		**33.332,8**
		Regional (<700 km)	1.833,3
		European (700-2,500 km)	5.553,3
		Intercontinental (>2,500 km)	25.946,2
Scope 3	**Catering**		**4.405,0**
			4.405,0
Scope 3	**Research expenses and consumables**		**9.362,9**
		Chemicals	1.899,2
		Congresses and symposia	2.157,4
		Gasses	730,5
		Intellectual property costs	1.386,9
		Other equipment & inventory	181,0
		Personal protective equipment	139,5
		Project costs faculties	3,6
		Scientific dissertations	347,6
		Symposium, Congress, Trade Fair	1.030,6
		Glassware/plastics/laboratory materials	1.486,4
Scope 3	**Administration, consultancy & auditing**		**55.600,8**
		Accountant fees	329,3
		Advertising costs	131,4
		Audit costs	13,7
		Collection costs	28,5
		Consultancy costs	1.695,6
		Inspections	4,6
		Insurances	1.373,8
		Interactive media	2,2

Unit	Average Emission Factor [kgCO2eq/unit]	Emissions [tCO2eq]	Note	EF Reference
€	0,34	52,2		b
€	0,39	39,0		b, c
€	1,27	669,2		c
€	0,77	0,5		b, c
passengerkm		**5.469,2**		
passengerkm	0,297	544,5		a
passengerkm	0,20	1.110,7		a
passengerkm	0,147	3.814,1		a
€	**1,14**	**5.428,6**	Calculated average emission factor	
€		5.428,6	Emission factor calculated separately	b
€	**0,56**	**5.036,0**	Calculated average emission factor	
€	1,07	2.022,7		c
€	0,15	323,6		c
€	0,67	489,4		c
€	0,13	180,3		b, c
€	0,52	94,1		b, c
€	0,40	55,8		b, c
€	0,34	1,2	Average emission factor from procurement	b, c
€	0,21	73,0		c
€	0,32	482,8		b, c
€	0,88	1.313,0		b, c
€	**0,15**	**4.476,4**	Calculated average emission factor	
€	0,11	36,2		c
€	0,19	25,0		c
€	0,08	2,6		c
€	0,14	4,0		c
€	0,16	271,3		c
€	0,11	0,5		c
€	0,17	233,5		c
€	0,52	1,1		b

Scope	Carbon footprint category	Description	Activity [x1000 units]
		Memberships	1.165,2
		Other equipment & inventory	113,8
		Other personnel costs	99,5
		Other staff advances	80,7
		Project costs university corporate offices	1.452,4
		Reception services	0,5
		Reimbursement for third-party services	28.260,0
		Reimbursement of moving and accommodation costs	0,8
		Reintegration costs	7,3
		Representation costs	136,6
		Shipping costs	564,8
		Staff recruitment costs	257,0
		Student insurances	0,3
		Study, education, and training	2.472,4
		Temporary workers	16.860,4
		Training costs for students	1,5
		Other office costs	548,7
Scope 3	**Transportation and travel**		**7.248,9**
		Accommodation costs of third parties	892,9
		Other equipment & inventory	5,2
		Project costs university corporate offices	85,5
		Transport and transport maintenance costs	251,6
		Transport means	119,9
		Travel and accommodation expenses abroad	1.690,0
		Travel costs applicants	23,3
		Travel costs untaxed km	310,3
		Travel expenses of third parties	2.737,3
		Domestic travel and accommodation expenses	835,5
		Means of transport rent	297,3

Unit	Average Emission Factor [kgCO2eq/unit]	Emissions [tCO2eq]	Note	EF Refe-rence
€	0,13	151,5		b, c
€	0,52	59,2		b, c
€	0,06	6,0		b
€	0,06	4,8		b
€	0,20	250,4	Emission factor calculated separately	b, c
€	0,17	0,1		c
€	0,06	1.696,3		b
€	0,42	0,3		c
€	0,13	0,9		b, c
€	0,34	46,5	Average emission factor from procurement	b, c
€	0,22	124,3		b, c
€	0,19	48,8		c
€	0,17	0,1		c
€	0,17	408,0		b, c
€	0,06	1.011,6		b
€	0,17	0,2		b
€	0,17	93,3		c
€	**0,53**	**4.318,5**	Calculated average emission factor	
€	0,42	375,0		c
€	0,52	2,7		b, c
€	0,48	40,6	Emission factor calculated separately	b, c
€	0,50	124,5		b, c
€	0,50	59,3		b, c
€	0,46	787,2		b, c
€	0,48	11,3		b, c
€	0,48	150,0		b, c
€	0,81	2.225,0		b, c
€	0,46	386,2		b, c
€	0,53	156,6		b, c

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Scope	Carbon footprint category	Description	Activity [x1000 units]
Scope 3	**Commuting**		
		Fossil fuel car	16.946,4
		Fossil fuel carpool	830,1
		Motorcycle	415,0
		Scooter/moped	415,0
		Train	5.810,4
		Bus /tram/metro (average)	1.245,1
		Bike	18.261,4
		Walk	830,1
Scope 3	**Energy supply to third parties on campus**		
		Natural gas	1.873,3
		Electricity	14.668,8
Scope 3	**Other**		**6.777,5**
		Description Unavailable	2.367,1
		Other equipment & inventory	1.600,7
		Project costs faculties	69,0
		Project costs university corporate offices	60,0
		Other facilities rent	790,3
		Student activity costs	360,1
		Maintenance of other consumables	301,4
		Mechanical works	1.228,9
Scope 3	**Paper products**		**2.727,7**
		Books	308,4
		Copy costs	371,5
		Loose purchase collection formation	247,1
		Other equipment & inventory	0,2
		Printing costs	1.798,2
		Project costs faculties	2,3

Unit	Average Emission Factor [kgCO2eq/unit]	Emissions [tCO2eq]	Note	EF Refe-rence
		4.065,6		
vehiclekm	0,22	3.728,2	Employee and student emissions	a
passengerkm	0,11	91,3	Employee emissions; 2 persons	d
km	0,137	56,9	Employee emissions	e
km	0,053	22,0	Employee emissions	e
passengerkm	0,006	34,9	Employee emissions	a
passengerkm	0,106	132,4	Employee emissions	d
passengerkm	0,00	0,0	Employee emissions	
passengerkm	0,00	0,0	Employee emissions	
		3.716,5		
m3	1,89	3.540,5		a
kWh	0,012	176,0	Emission factor of electricity generated through wind power	a
€	**0,26**	**2.368,0**	Calculated average emission factor	
€	0,34	804,8	Average emission factor from procurement	b, c
€	0,52	832,3		b, c
€	0,34	23,4	Average emission factor from procurement	b, c
€	0,37	22,1	Emission factor calculated separately	b, c
€	0,17	134,4		b
€	0,14	51,6		b, c
€	0,26	81,5		b, c
€	0,34	417,8	Average emission factor from procurement	b, c
€	**0,49**	**1.395,0**	Calculated average emission factor	
€	0,40	123,4		b
€	0,54	200,6		c
€	0,40	98,8		b
€	0,52	0,1		b, c
€	0,54	971,0		c
€	0,47	1,1	Average emission factor of paper products group	b, c

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Scope	Carbon footprint category	Description	Activity [x1000 units]
Scope 3	**Finance and tax**		**4.835,6**
		Administrative consumption expenditure	3.149,8
		Banking costs	0,1
		Paid interest	0,2
		Paid subsidies	1.650,0
		Project costs university corporate offices	20,0
		Various charges	45,7
Scope 1/2	**Electricity TU Delft**		
Scope 1		Electricity generation photovoltaic panels (LCA-based)	1.041,5
Scope 1		Electricity cogeneration	14.263,2
Scope 2		Purchase of wind energy (LCA-based)	52.602,5
Scope 3	**Waste**		**2.788,8**
		Recycled waste	1.201,8
		Waste-to-energy	1.194,6
		Landfill	392,4
Scope 3	**Water**		**167,1**
		Tap water (LCA based)	167,1
Total			

EF Reference

a Milieu Centraal; Stichting Stimular; Connekt; SKAO; Ministerie van Economische Zaken en Klimaat. (2018). CO2emissiefactoren 2018. https://www.co2emissiefactoren.nl/wp-content/uploads/2019/01/co2emissiefactoren-2018.pdf

b Adjusted from Vringer, K., Benders, R., Wilting, H., Brink, C., Drissen, E., Nijdam, D., & Hoogervorst, N. (2010). A hybrid multi-region method (HMR) for assessing the environmental impact of private consumption. Ecological Economics, 69(12), 2510–2516. https://doi.org/10.1016/j.ecolecon.2010.07.027

c Adjusted from Defra. (2014). Table 13 - Indirect emissions from the supply chain. UK Department for Environment, Food & Rural Affairs. https://www.gov.uk/government/statistics/uks-carbon-footprint

Unit	Average Emission Factor [kgCO2eq/unit]	Emissions [tCO2eq]	Note	EF Refe-rence
€	**0,15**	**775,7**	Calculated average emission factor	
€	0,17	535,5		c
€	0,14	0,0		c
€	0,14	0,0		c
€	0,14	231,0		c
€	0,14	2,8		c
€	0,14	6,4		c
		704,1		
kWh	0,07	72,9		a
kWh	-		Emissions calculated in category "Natural gas"	
kWh	0,012	631,2		a
t		**273,5**		
t		-195,0	EFs calculated separately based on TU Delft's waste processor	f, g
t		131,8	EFs calculated separately based on TU Delft's waste processor	f, g
t		336,7		h
m3		**97,8**		
m3	0,585	97,8		h
		105.938		

d Adjusted from Milieu Centraal; Stichting Stimular; Connekt; SKAO; Ministerie van Economische Zaken en Klimaat. (2018). CO2emissiefactoren 2018. https://www.co2emissiefactoren.nl/wp-content/uploads/2019/01/co2emissiefactoren-2018.pdf

e Stichting Stimular. (2018). Actuele CO2-parameters - 2018: Milieubarometer. https://www.milieubarometer.nl/CO2-footprints/co2-footprint/actuele-co2-parameters-2018/

f Renewi, TU Delft's waste processor

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h Pulselli, R. M., Marchi, M., Neri, E., Marchettini, N., & Bastianoni, S. (2019). Carbon accounting framework for decarbonisation of European city neighbourhoods. Journal of Cleaner Production, 208, 850–868. https://doi.org/10.1016/j.jclepro.2018.10.102

B. EVALUATION OF STUDY CASES REGARDING THEIR LIVING LAB CHARACTERISTICS [CHAPTER 3]

Case	**Real-world environment**	**Co-creation**	**Transdisciplinary approach**
Brains4 buildings	•••	•••	••
Development of new campus area	•••	••	••
E-bike charging station	•••	•••	•••
Geothermal well	•••	•••	•
Innovative facade	•••	•••	•••
Parking garage	•••	••	•••

••• High score
•• Medium score (still in line with expectations)
• Low score

Public-private-people partnership	Remarks
•	User involvement not yet defined or specifically integrated
• •	Specific living labs have to be developed and integrated into area development plans.
•	User behavior is monitored; however, they were not actively involved from the beginning.
• •	Even though campus operation (heat network) can be seen as the user actively participating, the neighboring residential districts, which are planned to be provided with heat as well, were not included. The research will be done on the geothermal well (disciplinary), whereas we see the living lab approach in the business case.
• •	The circular business model was designed and set up as a living lab but did not come into practice. The innovative façade itself is considered a testbed.
•	User involvement not yet defined or specifically integrated

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C. INTERVIEW DATA [CHAPTER 3]

Interviewee	Case	Date
Energy Transition Role	C	08.02.2021
Sustainability Role	F	22.03.2021
Project Coordination Role	A	27.05.2021
Academic Role	F	28.05.2021
Asset Management Role	B	31.05.2021
Academic Role	B	31.05.2021
Asset Management Role	D	01.06.2021
Real Estate Development Role	F	01.06.2021
Academic Role	A	08.06.2021
Academic and Advisory Role	C	02.12.2021
Academic Role	D	21.03.2022
Academic Role	E	22.03.2022
Academic and Advisory Role	G	23.03.2022
Project Coordination Role	E	24.03.2022
Innovation Management Role	G	12.04.2022

D. INTERVIEW GUIDELINE [CHAPTER 3]

- Could you tell me what the living lab is about and what goal it pursues?
- What is a living lab for you?
- Why did you choose a living lab setup?
- What are the opportunities and challenges of facilitating living labs on campus?
- What are the opportunities and challenges of the campus environment for living labs?
- How do you monitor your living lab?
- What impacts/consequences does your living lab have for the university organization?
- What were the biggest enablers and barriers in the process?
- If you had the chance to start over, what would you do differently this time?
- Is there anything left you would like to share or say?

E. SEARCH STRING [CHAPTER 4]

Search string for Scopus:
(("Living lab*") OR ("Urban living lab*") OR ("Real-world lab*") OR ("Transition lab*") OR ("campus lab*") OR ("Innovation lab*") OR ("campus innovation") OR ("sustainability lab*") OR ("Real-labor*") AND ("university") OR ("campus") OR ("higher education") AND TITLE-ABS-KEY ("success factor*") OR TITLE-ABS-KEY ("lesson* learned")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (LANGUAGE , "English"))

Search string for Web of Science:
(TS=(("Living lab*" OR "Urban living lab*" OR "Real-world lab*" OR "Transition lab*" OR "campus lab*" OR "Innovation lab*" OR "campus innovation" OR "sustainability lab*" OR "Real-labor*") AND ("university" OR "campus" OR "higher education")) AND LA=(English))

Further filter criteria in both cases: Articles only

F. INCLUDED ARTICLES [CHAPTER 4]

Articles included in the review:

Burbridge, M., & Morrison, G. M. (2021). A Systematic Literature Review of Partnership Development at the University–Industry–Government Nexus. *Sustainability*, *13*(24), 13780. https://doi.org/10.3390/su132413780

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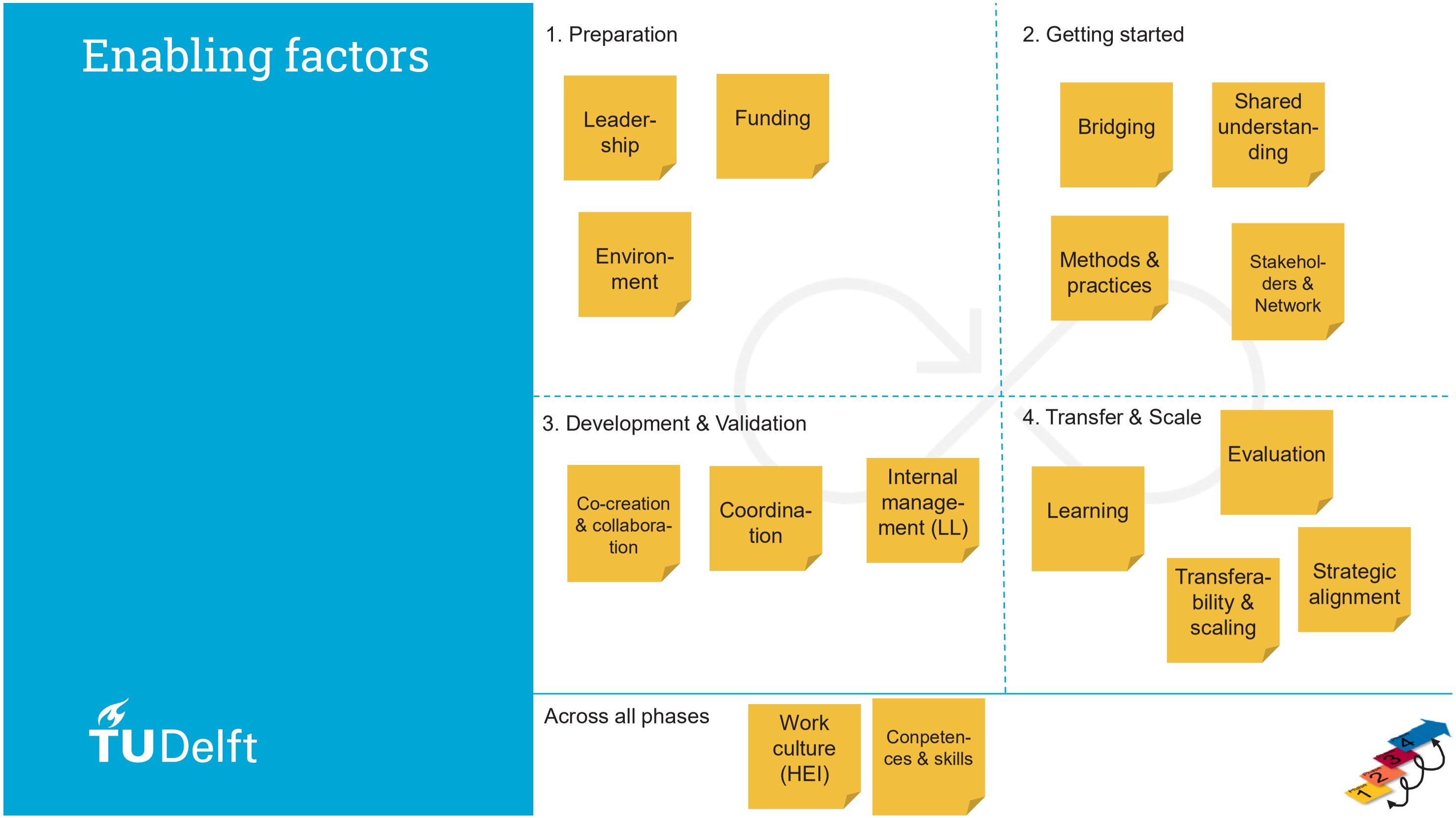
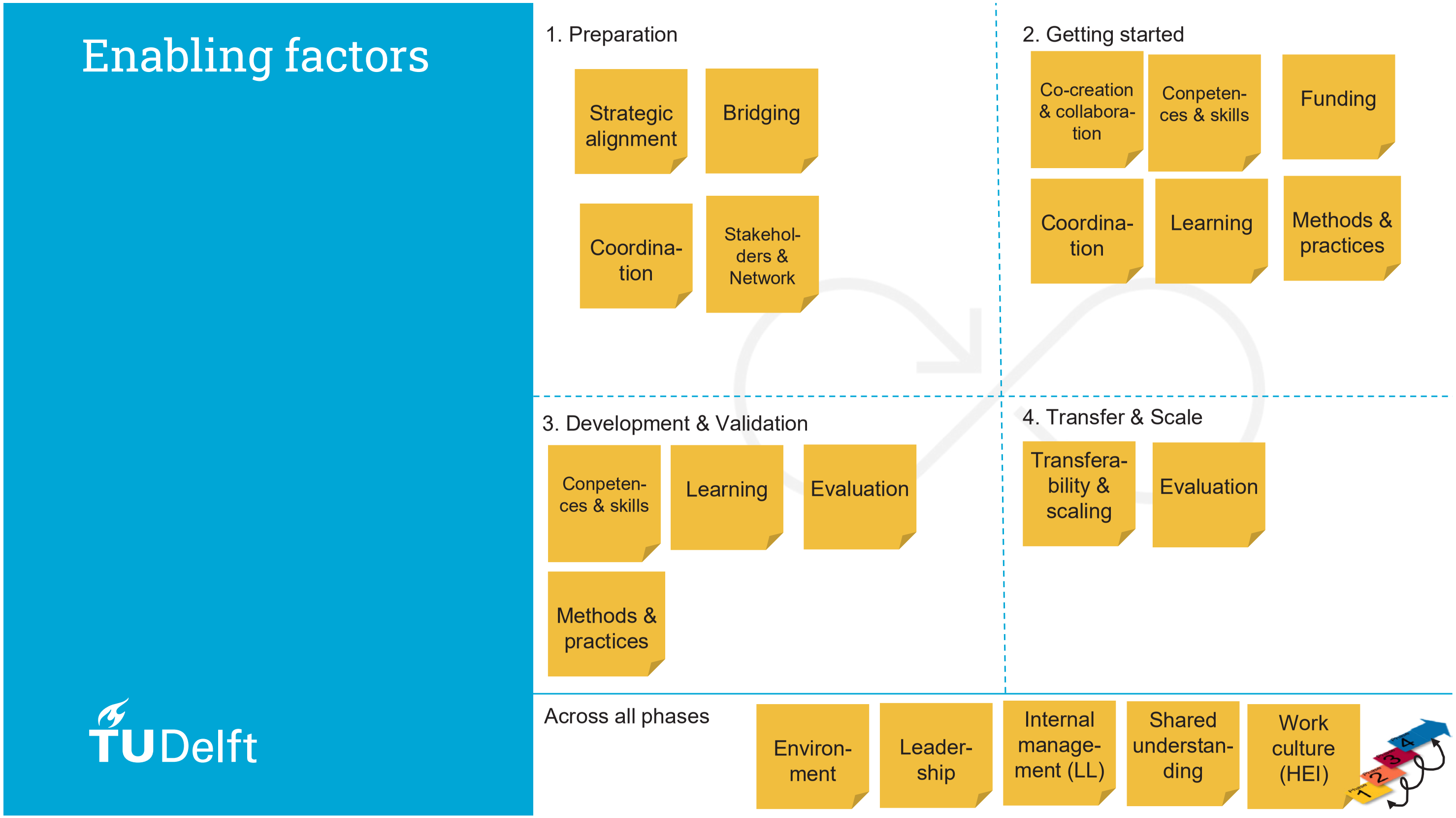
G. MAPPING PRESENTATION AND EXEMPLARY MAPPING [CHAPTER 4]

Blank mapping presentation:

Indicative mapping examples:




Enabling factors
TUDelft
1. Preparation
Strategic alignment
Bridging
Coordina-tion
Stakehol-ders & Network
2. Getting started
Co-creation & collabora-tion
Conpeten-ces & skills
Funding
Coordina-tion
Learning
Methods & practices
3. Development & Validation
Conpeten-ces & skills
Learning
Evaluation
Methods & practices
4. Transfer & Scale
Transfera-bility & scaling
Evaluation
Across all phases
Environ-ment
Leader-ship
Internal manage-ment (LL)
Shared understan-ding
Work culture (HEI)

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H. FLEISS KAPPA PER PHASE [CHAPTER 4]

Fleiss kappa per phase:

	Kappa	Z	Prob>Z
01 - Preparation	0.0448	0.82	0.2056
02 - Getting started	0.1390	2.55	0.0054
03 - Value creation	0.0730	1.34	0.0904
04 - Transfer & scaling	0.0204	0.37	0.3542

I. EXEMPLARY GUIDING QUESTIONS AND TASKS FOR THE CANVAS COMPONENTS OF PHASE 1 [CHAPTER 5]

This table is exemplary and non-exhaustive. Questions and tasks need to be adapted and complemented by relevant ones for a specific HEI setting. According to the flexible and fluid nature of a CaLL, questions and tasks may appear in various canvas components, and canvas components may overlap.

Analyze the existing setting (see Figure 5-3) of performing living labs/projects/testbeds/experiments on campus
• What is the current situation of our HEI regarding campus living labs, projects, testbeds, and experiments? (see Figure 5-3) • What are the values we gain currently and eventually with another approach? • Consider carrying out a SWOT analysis (see example in this chapter) • Do we have ambitions to move to a CaLL? • Would a CaLL be feasible, viable, and desirable? • How could current ongoing initiatives be integrated and onboarded? • How can the current momentum and resources be continued and further leveraged? • *Adapt these questions and tasks and complement them with your own*
Co-create a topic, a shared vision, and definitions for keywords to prepare a common ground and a communication strategy
• What is our shared understanding of a CaLL? • Which words do we use, and how do we define them? • Consider creating a glossary with core terms • What is the common interest of engaged parties? • What does "co-creation" entail? • Which participants need to be involved in the co-creation process of a vision for a CaLL? • What dilemmas and trade-offs can arise regarding the HEI's overall vision? • *Adapt these questions and tasks and complement them with your own*
Reflect on and map the availability of needed competencies and resources in the local environment
• Which specific competencies are needed in our local environment? • Do we have the competencies needed for the CaLL approach? • (e.g., developing capacities, reflexivity, transdisciplinary work modes, uncertainty/unknowability, conflict-resolving skills, ...)? • If not, how can we develop them? • Or which parties could provide or contribute to them? • *Adapt these questions and tasks and complement them with your own*

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Reflect on a possible governance structure to allow the creation of synergies while using existing structures
• What organizational structures and resources are available already? • Which loose ends can we connect to create buy-in? • Which governance structures do we have in our organization and networks? • How might a locally tailored governance structure look like? • *Adapt these questions and tasks and complement them with your own*
Screen and map your HEI's organizational structures, roles, positions, and obstacles regarding the chosen approach
• Which organizational structures exist already that can be used for a CaLL? • Which existing roles and positions can we include? • How can we leverage the existing structures and roles? • Which ones do we need to create? • Which obstacles are there? • Which resources are available? • *Adapt these questions and tasks and complement them with your own*
Identify relevant and critical stakeholders in and outside of your organization
• Who needs to be included in the process (internally and externally)? • Why are those stakeholders relevant? • Who has relevant expertise and resources in our organization and networks? • How does a CaLL approach align with the activities and interests of those stakeholders? • Where is it conflicting? • *Adapt these questions and tasks and complement them with your own*
Co-create a strategic frame for the CaLL setting
• Co-create the outlines of the CaLL's vision and mission relating to the HEI's overall strategy • Review and align with the HEI vision/mission for mandate and anchoring • Identify the possible impact, e.g., what will the benefits for society, education, and research be? • Draft the outlines of the CaLL's goals and consider already potential evaluation criteria and KPIs, e.g., scalability, transferability, policy-making, continuity, stacking, series of activities, … • Develop a first draft timeline for reflection moments and feedback loops • When are natural and defined reflection moments to revisit and adapt the created artifacts (structure, governance, vision, goals, evaluation moments) according to installed feedback loops? • Which coordination structures will be needed? • Which criteria are we using for decision-making? • Who has the mandate to take go/no-go decisions? • How can a CaLL identity be created? • *Adapt these questions and tasks and complement them with your own*

Explore financing possibilities and schemes
• How will the funding structures be organized? • What pools of funding can be leveraged? Create an overview. • How will the CaLL be financed? (e.g., subsidies, own funding, specialized funds, shared financing, ...) • What financing opportunities do the stakeholders have? • What are financing conditions? • Initiate and engage in an early dialogue with stakeholders on their possible financial involvement • *Adapt these questions and tasks and complement them with your own*
Clarify and name explicitly the shared interest to motivate engagement
• What is the common interest of engaged parties? • Why should parties engage? • What are the values and benefits for all parties? • Which topics and outcomes reflect those values and benefits? • *Adapt these questions and tasks and complement them with your own*

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J. EXEMPLARY GUIDING QUESTIONS AND TASKS FOR THE CANVAS COMPONENTS OF PHASE 2 [CHAPTER 5]

This table is exemplary and non-exhaustive. Questions and tasks need to be adapted and complemented by relevant ones for a specific HEI setting. According to the flexible and fluid nature of a CaLL, questions and tasks may appear in various canvas components, and canvas components may overlap.

Co-create the visions/mission statements and develop success indicators
• Use all the relevant ideas, drafts, and outcomes of Phase 1 to fine-tune and define during this phase • What are the CaLL's vision and mission statements? • How do the stakeholders' goals relate to the CaLL vision? • Which success indicators are we handling? • With which indicators will we measure if we reach our goals and impacts? • How is the CaLL anchored in the vision/mission of the HEI? • How do the success indicators respect and align with the stakeholders' views? • *Adapt these questions and tasks and complement them with your own*
Establish a governance structure for the CaLL, including mandates, roles, and responsibilities
• Who is coordinating the CaLL? • Who are the involved parties? • What mandates are/should be formulated and given to whom? Is a clear mandate received? (e.g., power to take actions, resources, …) • Is the mandate operationalized? (e.g., build up a team, talk to relevant actors, communicate existence) • Are governance structures and roles defined (with the help of the mandate)? • Who is involved in the CaLL steering committee? • Who is involved in the CaLL advisory board? • Who will coordinate, store, and process data on the CaLL level? • Decide how and who can suggest initiatives/projects/experiments within the CaLL • Define selection processes • Is there a need for a code of conduct for the CaLL? If so, define it. • Consider having conflict management schemes • *Adapt these questions and tasks and complement them with your own*

Perform foresight analysis/assessment
• What impact do we want to have with the CaLL? • How often and when will the CaLL be (re-)assessed? • How does the CaLL contribute to the HEI's sustainability aims and its sustainability transformation? • Where are opportunities to foster the transfer and/or scaling of innovations and other outcomes? • How can new opportunities be co-created based on the existing partnerships? • What new opportunities could emerge during CaLL? • How can new insights be leveraged? • How can we design for cross-fertilization and serendipity? • *Adapt these questions and tasks and complement them with your own*

Perform risk assessment and plan iterative evaluation cycles
• Which risks could arise when CaLL is running? • How do we handle those risks? • Which alternative solutions do we have in place? • Which alternative solutions can be created? • Who is responsible for the iterative risk assessment? • How often and in which timeframe are we reevaluating? • *Adapt these questions and tasks and complement them with your own*

Identify processes, goals, and timelines to realize initiatives/activities
• Which initiatives and activities fit our CaLL portfolio? • How are initiatives selected? • Create a plan for their timeline and their goals • Which processes are there from initiation to completion? • Which (universal) reporting structures are there? • How and when are the initiatives evaluated? • How are interlinkages and cross-fertilization facilitated? • Which data is collected from the different initiatives and activities? • What data is shared? • *Adapt these questions and tasks and complement them with your own*

Incorporate intellectual property management and data democratization processes
• How do we deal with intellectual property? • Who needs to be involved in those processes? • Who will coordinate, store, and process data? • Who is allowed to access the data? • Is a mediating party nominated in case of conflict? • *Adapt these questions and tasks and complement them with your own*

Establish a "living lab positive" work culture in the organization

- Which established ways of inter- and transdisciplinary working can we enforce?
- Which new ones need to be created?
- How can we create that change?
- Who do we need to create that change?
- Engage in targeted communication to reach the attention and understanding of the CaLL's value
- Develop/strengthen transdisciplinary working and knowledge-sharing processes and structures
- *Adapt these questions and tasks and complement them with your own*

Establish systematic learning structures

- In which ways will we share and transfer our knowledge?
- Which learning networks are in place already?
- Which ones do we need to create?
- Who will manage the knowledge and how?
- What have parties learned from each other?
- What have parties learned in the process?
- How is the internal and external learning network set up?
- When are natural reflection and evaluation moments?
- How are they integrated into the previously defined structures and processes?
- How will we facilitate cross-fertilization?
- Strengthen learning across disciplines and sectors
- How will the gained learnings and knowledge be fed back and integrated into the HEI organization?
- *Adapt these questions and tasks and complement them with your own*

Establish tailored (science) communication strategies

- With which interest groups do we need to engage?
- In which ways are we communicating to those groups (channels, modes, frequency, content, …)?
- Are resources foreseen to allow tailored communication strategies?
- How is this communication integrated into the CaLL processes and activities?
- *Adapt these questions and tasks and complement them with your own*

Allocate resources

- What are the internal and external financing options and schemes?
- Which timeframes are handled?
- What are the demarcations and localizations of the CaLL?
- Do we have the right and sufficient human resources/staffing? (see defined competencies and skills)
- Are existing teams and positions engaged, and were they adequately onboarded?
- Is there a database available to match initiatives/activities to researchers and other parties and the other way around?
- Where can we establish alliances and partnerships across intra- and extra-organizational boundaries?
- Which partners we have not identified in the previous phase are important?
- Who can be involved in identifying those potential new partners?
- How can the continuity of the CaLL be ensured?
- *Adapt these questions and tasks and complement them with your own*

Chapter acknowledgments

CHAPTER ACKNOWLEDGMENTS

Each chapter would not have been possible without the invaluable assistance and support of numerous individuals. Here, I would like to dedicate a special thank you to those who helped along the way.

Chapter 2
Thanks are extended to TU Delft offices and faculty staff, as well as the university service providers for waste and catering, for their help in providing data and assisting with its analysis, calculation, and interpretation. This work would have been impossible without them. Gratitude is also expressed to the two anonymous reviewers and the deputy editor for their constructive feedback.

Chapter 3
Thanks to all the interview partners for their time, openness, and trust. Your invaluable insights and candidness have made this work possible.

Chapter 4
Thanks to the experts who contributed to the factor mapping and provided valuable discussion points and feedback. A special acknowledgment goes to Aline Lohse and Vladimir Sobota for their valuable peer-to-peer feedback and their considerate and friendly support during the development of this study.

Chapter 5
Thanks to Ivona Bossert and Nina Bohm for their contribution to the graphic designs. Thanks to Robert Verburg and Kornelis Blok for their constructive feedback and comments on earlier iterations of this chapter.

Acknowledgments

ACKNOWLEDGMENTS

Colleagues told me that writing their acknowledgment sections was the most enjoyable part of a thesis, but here I am, staring at a blank page just days from the submission deadline. How do I even begin to describe the support, guidance, encouragement, motivation, inspiration, and constructive criticism that enabled me to grow throughout the last few years? How do I capture the impact of the ripple effects from a great conversation, a grounding yoga class, weekend hikes in good company, a refreshing vacation, or after-work laughs?

A panacea for any challenge I encountered during my PhD journey is returning to a quote that became a motto—"Maak het niet ingewikkelder dan het is" (Don't make it more complex than it is). This motto has been on my office wall since the start. In blank-page moments like this, I give my best to come back to it. So, I will follow that advice again and keep it simple: Without the amazing people around me, there would be no reason to sit here and fill this page. Without you, this thesis wouldn't exist. Thank you!

To my promotors, Robert and Kornelis, thank you for helping me grow, both professionally and personally.

Kornelis, the quote above could only have come from you. I admire your sharpness in breaking things down to the core while respecting their complexity. From day one, you met me at eye level, encouraged me to spread my wings, and supported me even when I deterred quite substantially from the path you likely envisioned. Thank you for trusting me to find my own way. I admit I may not have made it less complex. Your groundedness always stood out to me; you took me seriously at all times and were there exactly when I needed it. Thank you for providing the space and trust when I almost gave up.

Robert, I was caught by your contagious enthusiasm and excitement from the first meeting we had. It was this enthusiasm that carried me through the years. Your motivation and belief helped me believe in myself. I admire your honest perspective on life and academia, always with a winking eye. Thank you for seeing the colorful sides of what often felt like black-and-white tasks and for embracing all the colors I used when trying to make sense of things. Our conference trip to Pisa stands out—not only for the light blue office cup we now both love but for how that experience helped me find my peers, sparking inspiration and motivation. I enjoyed working and laughing with you, both in great balance.

This work wouldn't have been possible without the corporate office Campus Real Estate and Facility Management. Being part of the first sustainability team during my first years gave me valuable insights into the organization and the great ambition of people to create a more sustainable, climate-neutral, and circular campus. Special thanks to Hubert, Sem, Sander, Bob, Gilbert, and Maria for your continuous efforts to reach that goal.

Thanks also to the secretaries, without whom I would have been lost from the start. Priscilla and Diones, thanks for your warmth, dedication, open ears, understanding, encouraging smiles, and support with any kind of issue I had.

To the Energy & Industry group, thank you for making this such a wonderful place to work and collaborate. The warm, welcoming atmosphere you have all created is unmatched, and I'm grateful to have been amongst you all.

Emile, thank you for brightening my day whenever we crossed paths, whether at the coffee machine or chatting by your door. Thanks for cheering me on and for your empathy, excitement, and valuable professional and personal tips. You set an inspiring example by keeping joy and playfulness alive in both grown-up life and the rather serious work we do. And a special thanks to Charlotte for being part of my journey, too, through stories or in presence. Seeing how much your dad lights up when he talks about you and Arthur is heartwarming.

To all the past and present PhD students at TU Delft and beyond who made all the difference. A special thanks to Aline, Amit, Arthur, Fernando, George, Ivan, Jannis, Javan, Kasper, MaJo, Mathew, Ni, Özge, Rami, Roman, Shahrzad, Shyrle, Sina, Vitto, Vladimir, and Wiebke for countless coffee breaks, lunch chats, sharing insights, utter silliness, heartwarming laughter, hikes through the Alps, co-working sessions, peer feedback, virtual drinks during COVID lockdowns, pancake afternoons, last-minute proofreading, beach trips, spending office time together, Thursday drinks, writing retreats, building confidence and sharing uncertainty, sotto casa and flying slippers, and support during tough times. In short, thank you for sharing the ride!

To the Architecture Faculty PhDs, who welcomed and adopted me warm-heartedly in the final stretch. Anna, Felipe, Maarten, and Mart, thanks for having me.

Fien and Svenja, thank you for creating the coziest workplace at TPM. You made me want to come in day after day. Thanks for making our office a safe space for the full range of emotions, celebrating the highs, acknowledging the lows, and keeping an eye out for each other's balance. I cannot wait to see where the three of us end up. In any case, consider this my official application for an internship with you.

Thanks to the CoP MoLL participants and especially the CaLL subgroup. Nina and Michael, thanks for most likely the smoothest and most joyful co-authoring the world has seen. Your inspiration, support, effort, and genuine care made me feel like I had a team out there. Thanks for all the fruitful discussions, great co-creation, and endless but fun rounds of text ping-pong we played!

Arthur and Katia, thank you for hosting me at your French castle, a trip that still vibrates warmly when I think back. Thank you for your friendship, kind words, warmth, calmness, and wisdom. Arthur, I proudly inherited your office desk and am glad to have you by my side as I defend what I have written all these days, peeking at the TU Delft Aula.

Mathilda and Dirk, I admire how you ride the waves of life; you are a shining example that love and faith can conquer all. Thank you for welcoming me into your family and regularly feeding me physically and mentally after long weeks of writing. Sharing your warmth, light, and laughter has been a gift.

Nina, we both know the figures in this thesis would not be half as nice without you—if they existed at all. I have enjoyed every step we have taken together, both literally and figuratively. Here is to many more small steps that turn into beautiful hikes, and to remembering to pause and appreciate what we have accomplished. Thank you for your continuous support, motivational words, putting things into perspective (it's all a matter of toe length), and for enjoying all the "nothingness" we created during intense writing times. Jetzt ist Feierabend.

Harm, Merel, and Anne, a heartfelt thank you for all your navigational guidance. I cannot express how grateful I am to have had you walk by my side as I grew from the person I was at the start of this journey into who I am today. This book would not exist without you.

To my closest friends, from near and far, thank you for always showing up for me, patiently listening, your perspectives, honesty, and warmth, and for holding a space for me. You have been my tribe and my home base. I could not have done this without you, and I am happy to have each of you in my life.

Oma Tick-Tack, aside from making the best pancakes in the world, thank you for all the care packages, thoughtful gifts, and Black Forest treats you sent my way. Still, no “Vesper” tastes as good as in your company at your kitchen table. Thank you for your unmet hospitality, patience, and understanding during the first COVID-19 wave, when I extended my stay again and again—and again. I hope to be as sharp and fit as you are when I grow up. And to my grandpa, I would have loved to share every detail about this journey with you. Down to what time I woke up and what I had for breakfast.

A heartfelt thanks to my parents for always having encouraged me to embark on any adventure. Mutz, thank you for always being ready to be there whenever I needed it, for your exceptional care, and for hosting me in your nature writing hut, where the first draft of Chapter 3 took shape. Papa, thank you for your unique and refreshing perspectives, authenticity, and loyalty and for taking my mind off things during our weekly phone calls.

Adri, seeing you grow and look life straight in the eye is incredible and inspiring. You have the courage and strength not to shy away but rather turn your whole life upside down for the better. Just as you have supported me throughout the process of writing this dissertation, I am cheering you on proudly.

From my promotors and colleagues to family and friends, you all played a vital role. Every conversation, laugh, kind gesture, and moment of support, from the smallest to the most significant, helped me move forward. This thesis is now filled with many written pages instead of blank ones, thanks to each of you. As I reflect on everyone I have thanked, I am aware that this journey was not just about research—it was about community, connection, and, well, not giving up.

I am deeply grateful to be surrounded by such wonderful people—this is to all of you!

List of Publications

LIST OF PUBLICATIONS

Peer-reviewed publications

Herth, A., & Blok, K. (2023). Quantifying universities' direct and indirect carbon emissions – the case of Delft University of Technology. *International Journal of Sustainability in Higher Education*, *24*(9), 21–52. https://doi.org/10.1108/IJSHE-04-2022-0121

Herth, A., Verburg, R., & Blok, K. (in press). How can campus living labs thrive to reach sustainable solutions? *Cleaner Production Letters*.

Herth, A., Verburg, R., & Blok, K. (in press) The Innovation Power of Living Labs to Enable Sustainability Transitions: Challenges and Opportunities of On-Campus Initiatives. *Creativity and Innovation Management. Advance online publication. https://doi.org/10.1111/caim.12649*

Herth, A., Vogel, N., & Bossert, M. (in press). From Living Labs on Campus to the Campus as a Living Lab – A Tool to Support the Sustainability Transformation of Universities. In W. Leal Filho, J. Newman, A. Lange Salvia, & L. Viera Trevisan (Eds.), *North American and European Perspectives on Sustainability in Higher Education: World Sustainability Series*. Springer.

Conference contributions

Herth, A., Dijkstra, A., & Vogel, N. (2021, June 22). *Impact and lessons from a global Community of Practice on Monitoring Living Labs*. Amsterdam Institute for Advanced Metropolitan Solutions, Urban Living Lab Summit (virtual), Amsterdam, the Netherlands.

Herth, A., Verburg, R., & Blok, K. (2021, October 6–8). *The campus as a living lab to foster the energy transition*. 12th International Sustainability Transition Conference: Mainstreaming sustainability transitions: From research towards impact (virtual), Karlsruhe, Germany.

Herth, A., Verburg, R., & Blok, K. (2022, September 11–13). *Enabling innovations for the energy transition: The university campus as a living lab*. 23rd CINet Conference: Pursuing innovation for a smart & sustainable future, Pisa, Italy.

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Herth, A. (2022, October 5–6). *Living labs for the energy transition: Critical perspectives on the notion of living labs*. SLU Urban Futures Conference: Getting our cities right #2: From living laboratories to urban healthscapes, Alnarp, Sweden.

Herth, A., Verburg, R., & Blok, K. (2022, November 21–25). *The influence of campus living labs on the energy transition – A meta-analysis*. 13th International Sustainability Transition Conference (virtual), Stellenbosch, South Africa; Melbourne, Australia; Washington DC, USA.

Herth, A., Vogel, N., & Bossert, M. (2023, June 6–8). *Universities as living labs: Sustainability transformation and community resilience*. 16th International Sustainable Campus Network Conference, Mexico City, Mexico.

Herth, A., Vogel, N., & Bossert, M. (2023, October 2–4). *A tool to support universities: From living labs on campus to the campus as a living lab*. Transatlantic Symposium on Sustainable Development: North American and European perspectives on sustainability in higher education, Cambridge, MA, USA.

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Hänsch, M., Nijs, G. de, Redouani, S., & Herth, A. (2020). *Notitie Verduurzaming Campus*. TU Delft.

Hänsch, M. (2020). *KPI's en Criteria: Verduurzaaming Campus TU Delft - CRE*. TU Delft.

van den Dobbelsteen, A., & van Gameren, D. (2021). *Sustainable TU Delft: Vision, ambition and action plan*. TU Delft. https://filelist.tudelft.nl/TUDelft/Research%20sites/Sustainability/Sustainable%20TU%20Delft%20-%20Vision%20ambition%20and%20action%20plan%20v5.3_220927.pdf

About the Author

ABOUT THE AUTHOR

Annika obtained a double Bachelor's degree in International Business and Languages from Avans University of Applied Sciences in Den Bosch, the Netherlands, and the University of Savoie Mont Blanc in Annecy, France. Through an exchange semester in Mexico and internships in France and Germany, she gained hands-on experience in international business, intercultural communication, and stakeholder engagement.

Annika earned a Master's degree in International Management with distinction from the Technical University of Dresden, where she specialized in Environmental and Sustainability Management. During her studies, she interned at the Brussels-based representation of a national federation, representing the waste management, water, and raw materials sectors. This internship enabled her to interact with various stakeholders at the European level on environmental policy, which further developed her expertise in sustainability frameworks and circular economy strategies. Later, her master's thesis explored circular business models in the textile industry.

For her PhD, Annika joined the Delft University of Technology, working with the Corporate Real Estate and Facilities Management office and the Faculty of Technology, Policy and Management. During her doctoral studies, she led a project to assess the photovoltaic potential on campus, leveraging the university's research expertise. She also advised various departments on collaborative projects, such as calculating the university's carbon footprint with the Finance office and providing guidance on the Campus as a Living Lab initiative. This work paved the way for further research and operational collaborations, including developing sustainable procurement strategies and campus innovation frameworks.

As an active member of research networks and a Community of Practice focused on living labs, Annika has published on sustainable co-creation and innovation in higher education contexts. The frameworks developed in this thesis, presented at the 2023 International Sustainable Campus Network conference, sparked interest from Higher Education Institutions worldwide. This led to the formation of a global Community of Practice around the Campus as a Living Lab, hosted by the ISCN. Now, comprising over 45 high-ranking institutions, this Community of Practice builds on the conceptual foundations established in Chapter 5 of this thesis.